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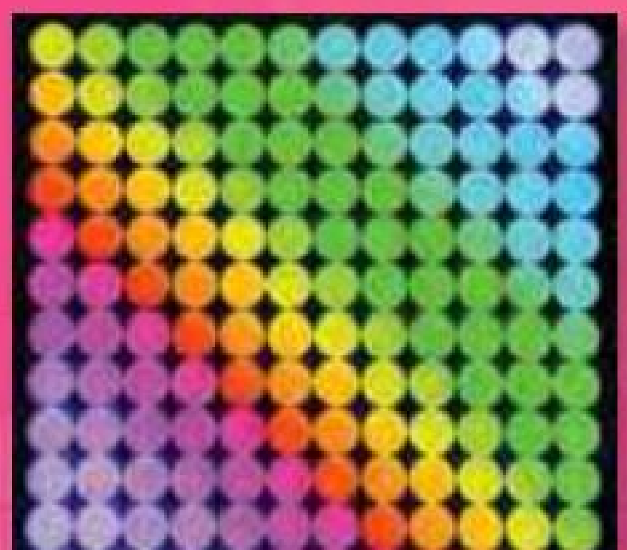

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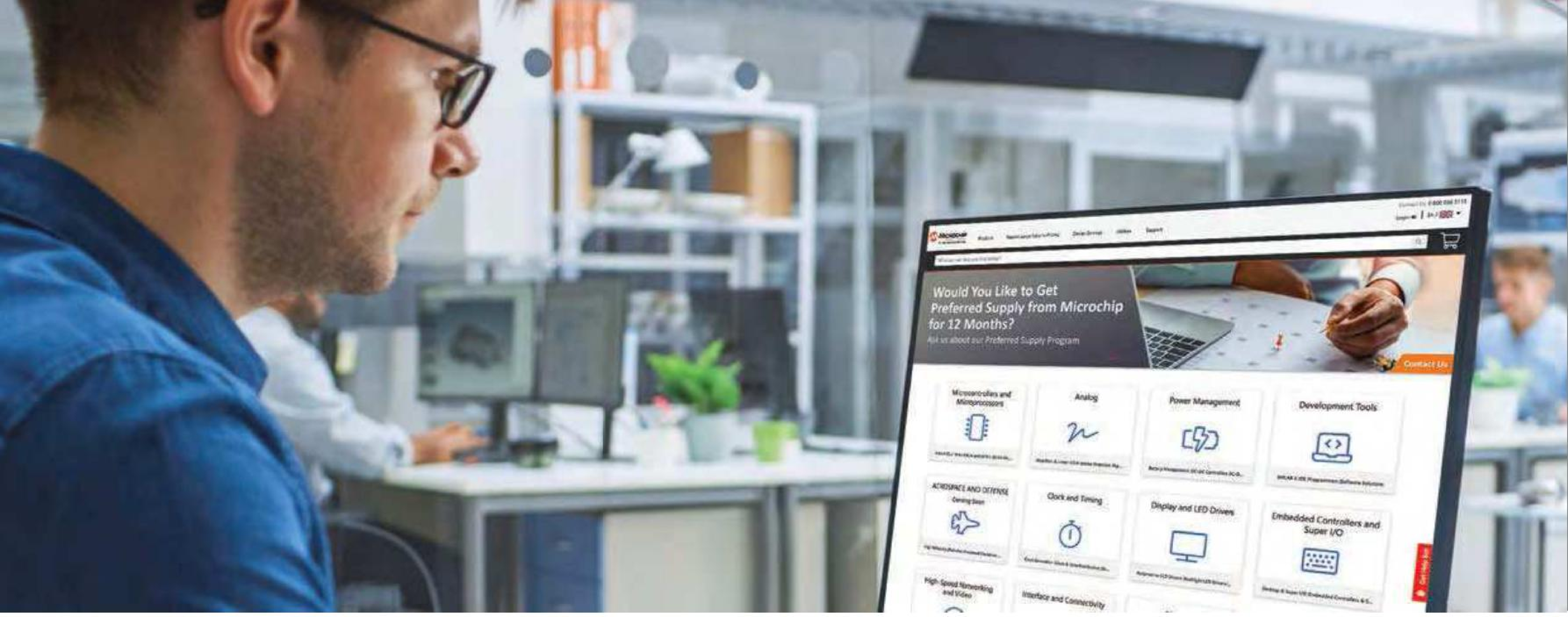
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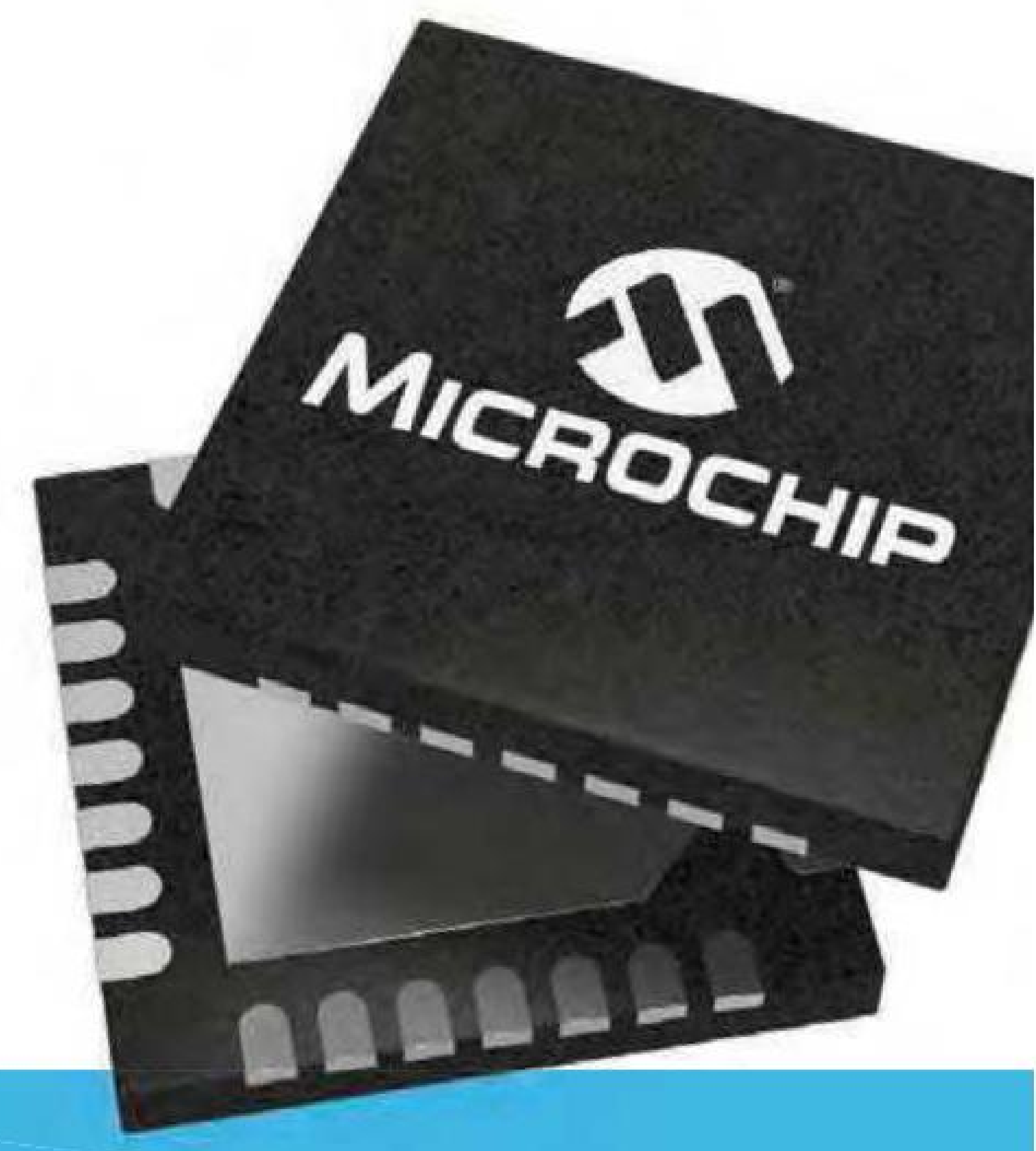

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Perform remote control sequences for TV, DVD, pay-TV and Internet streaming at the press of a single button using the Infrared Remote Control Assistant.

Touchscreen Wide-range RCL Box – Part 2 by Tim Blythman 32
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WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

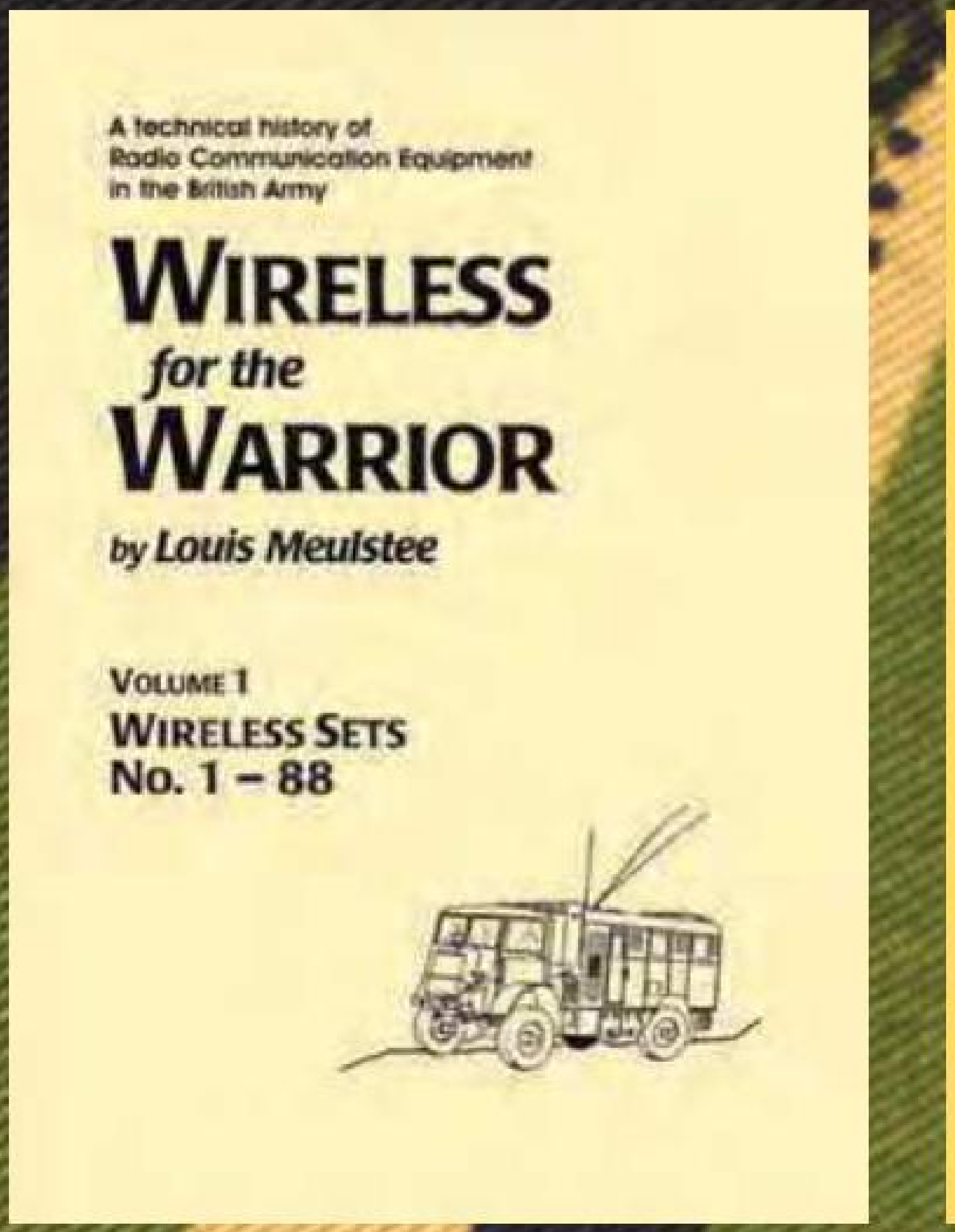
The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



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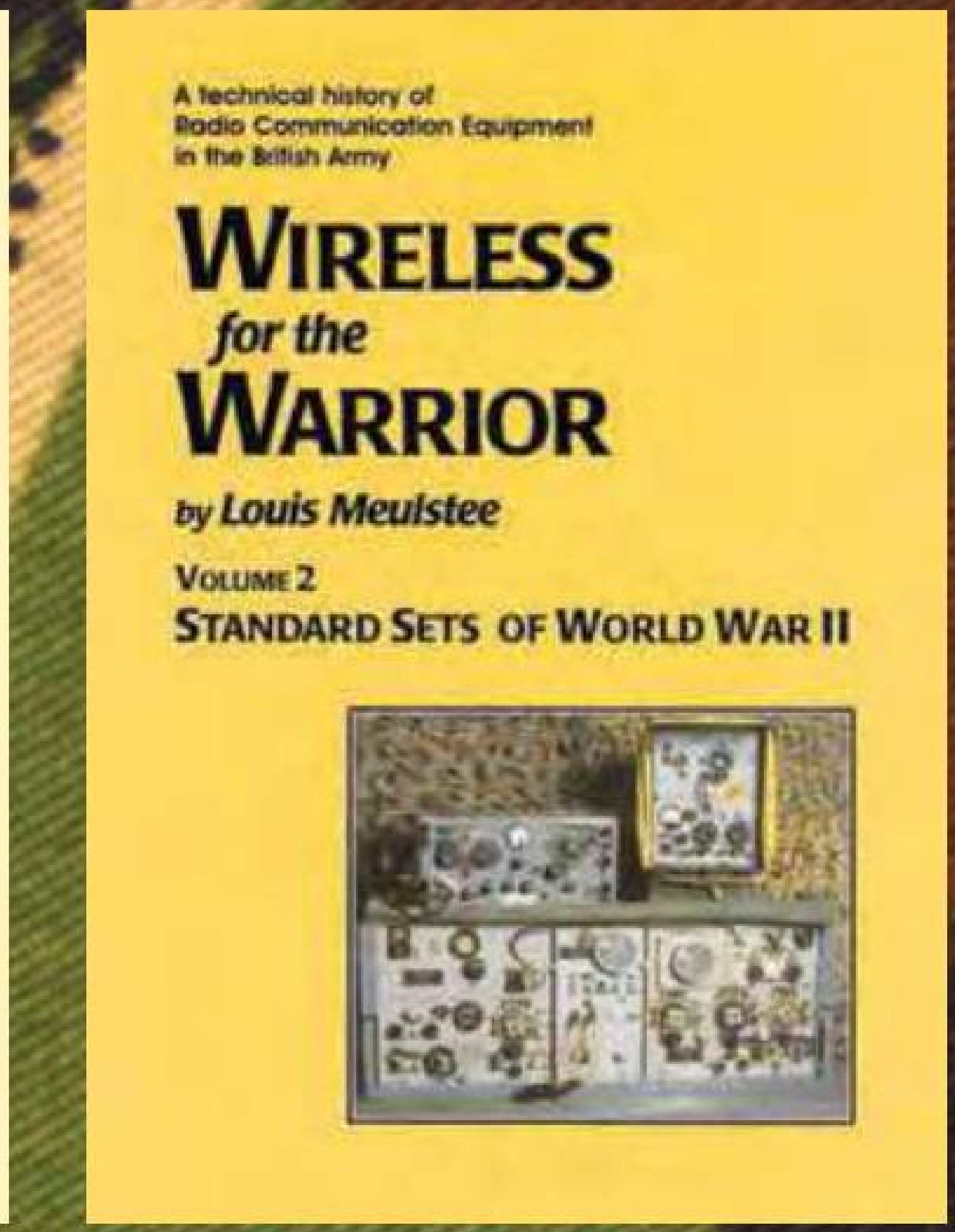

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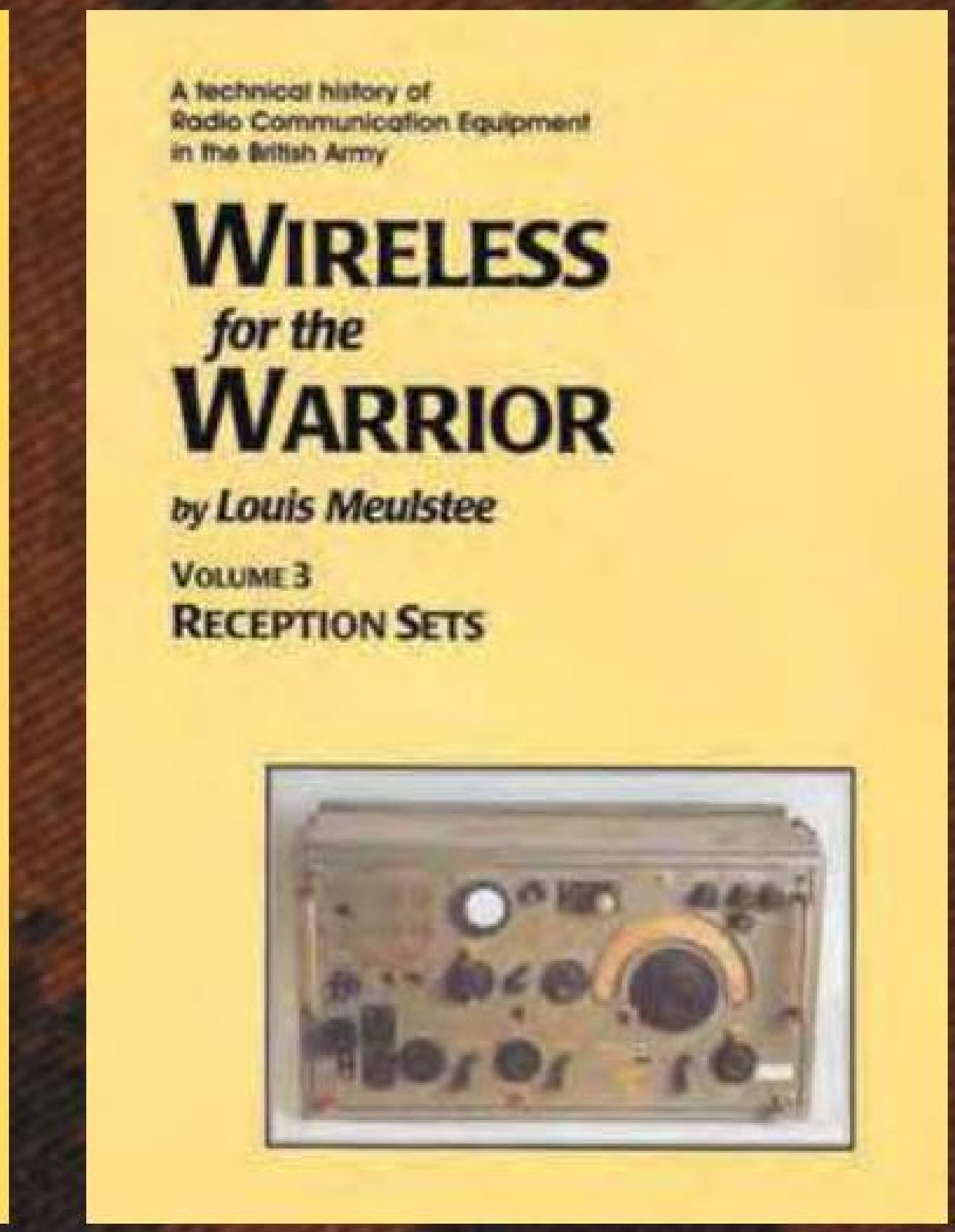

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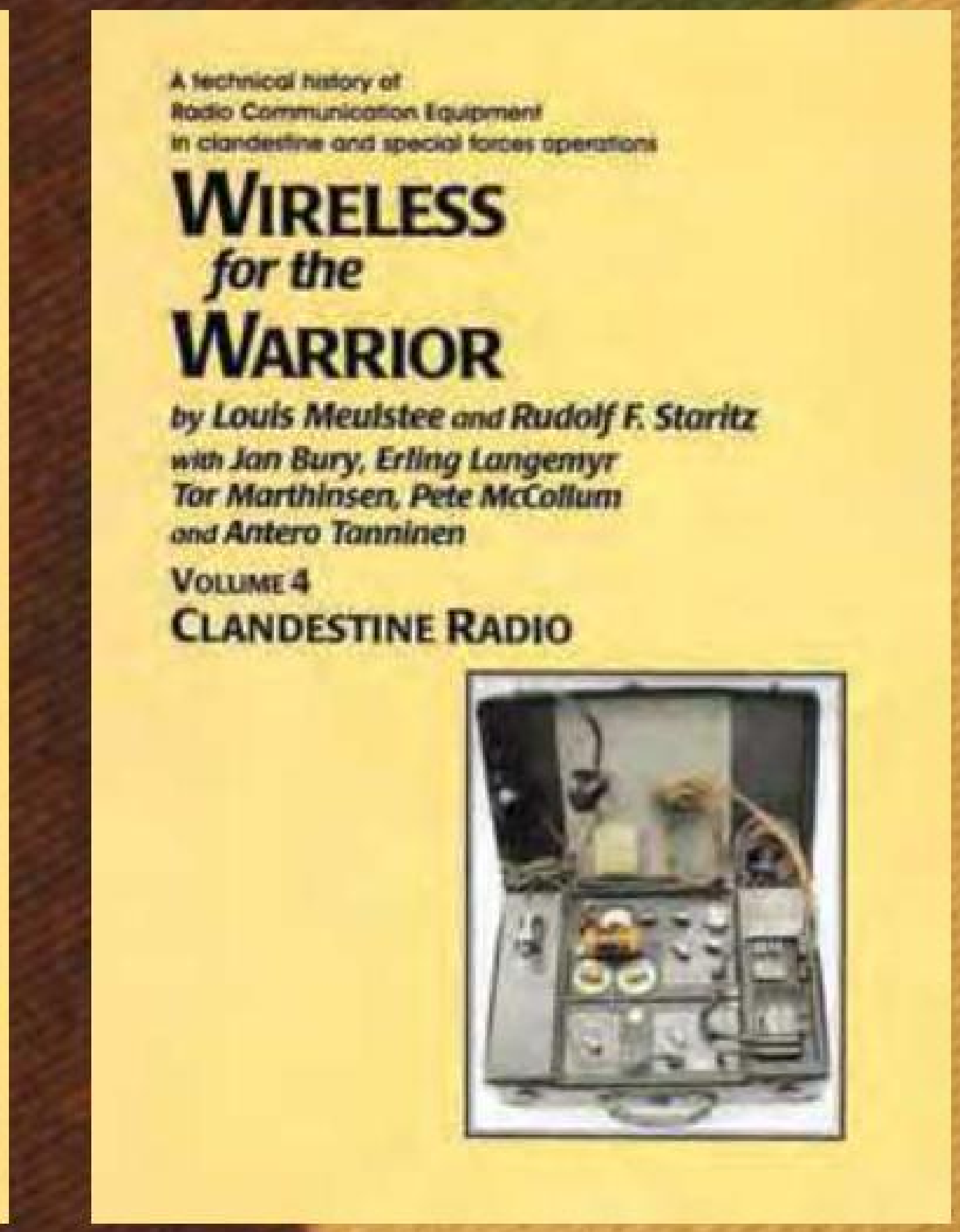

A technical history of Radio Communication Equipment in clandestine and special forces operations

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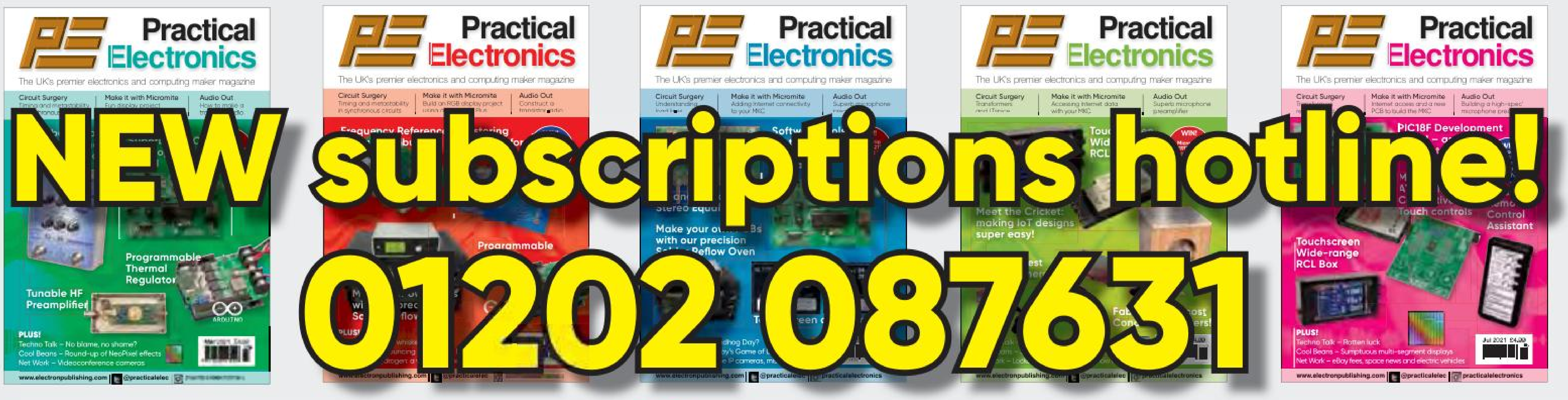

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Welcome to the Audio Out Shop

We are introducing a new and very useful reader resource on page 43 of this month's *Practical Electronics*. Meet the brand-new 'Audio Out Shop'. It does exactly what it says on the tin – it's a shop for those of you who enjoy audio electronics and esoteric analogue design. It's entirely run by *Audio Out* columnist Jake Rothman, who is drawing on his vast collection of rare, unusual, hard-to-find and just plain useful parts.

Whether it's components for Theremins and preamplifiers, or his recent take on the Ladybird Radio, you can find all the parts you need to complete Jake's designs from his strictly analogue electronic emporium. His advert is not an exhaustive list, just an edited highlights of parts most likely to be useful to *PE* readers – for example, the germanium transistors or audio-grade capacitors regularly referenced in his articles. What's more, if you can't find something for your own design or restoration project then drop him a line or give him a call, he may well have just what you're looking for. If he doesn't have it then he can probably suggest an alternative part or know who else might stock your elusive component.

Support the other independent sellers too!

Do remember that small-scale niche sellers who advertise in *PE* have had a pretty tough time of it recently – haven't we all? It's so easy to just click a mouse and buy everything from eBay and Amazon, but it's not always the best, cheapest or quickest way to buy parts. If you get a chance to support any of our advertisers – Quasar, Cricklewood, JPG or ESR – then you're not just helping a real shop, but keeping alive the group of increasingly rare vendors dedicated to supporting our hobby with proper old-fashioned service and real knowledge of parts and components.

Keep well everyone

Matt Pulzer
Publisher

The Fox Report

Barry Fox's technology column

One game-changer – one probably not

Are you a phone-does-it-all person? Or (like me) a horses-for-courses computer, digital SLR and phone person?

Yes, the processing power of smart phones is phenomenal and the camera optics of espionage quality. But some of us still feel more comfortable with a large screen and chunky keyboard. A DSLR with see-through viewfinder is much easier to hold steady and phone screen finders are 'washed out' by sunlight. Inadvertently touching the wrong part of the phone screen all too easily changes the camera settings. Phone zoom lens have limited range and the tiny sensors struggle with low light.

Two recently launched phone ranges looked like possible game changers. One definitely is, the other… is still to be determined.

Voice to text

It was a journalist colleague who, like me, had for years been using a Livescribe pen to record interviews, who discovered a seriously clever feature called Recorder in Google's new Pixel range of phones. Pixel Recorder gives near-instant transcription of a speech recording into editable text.

As a reminder (if you ever knew), Livescribe was a very smart pen with built-in microphone and speaker, which wrote on special paper over-printed with a near invisible location map. Infrared optics and memory in the pen captured an image of the words written, along with the matching audio. So the pen stored the sound of an interview and a mapped image of notes written.

The Pixel – a transcribing game-changer?

Tapping the pen on the paper notebook, replayed the matching audio. After copying to a computer, the text displayed on screen and the recording played through speakers. Touching a word with the cursor jumped playback to around the same place in the audio.

The only let-down was the difficulty of converting the captured writing image into editable text. Before this problem was solved, the Livescribe company went off at tangents (including marketing a pen called, 'Sky' which the satellite broadcaster's lawyers inevitably saw off) and then faded from view.

Pixel Recorder

Although it is not promoted as such, Pixel Recorder realises the Livescribe dream, and takes it to another level, by recording audio and in real time accurately converting it into editable text, with astonishing accuracy.

I borrowed a Pixel 4 phone and ran a very simple test. I sat the Pixel alongside a PC, went into YouTube, found a TV interview (Irish-dialect Peter O'Toole telling showbiz stories to American-dialect David Letterman) and let Recorder record it. Almost immediately a transcript of the conversation scrolled up on the phone screen, with only a very few very minor mistakes.

Normally, the kind of processing needed for this trick will rely on remote computer power and intelligence 'in the cloud' and thus depends on a broadband connection. But not in this case; all the work is being done inside the phone. I checked this by putting the

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Pixel phone in Flight Mode. Real-time transcription did not stop. So, Google's Pixel Recorder really is a game-changer.

My only regret is that there were no Pixel phones with Recorder processing available 10, 20, 30 years ago when I was travelling round the world, taping interviews and recording press conferences, followed by dreary hours in a hotel room trying to accurately type up what I could discern from the tapes.

I checked with Google and can confirm that the Recorder function comes 'out of the box' on Pixel 2 and later Pixel phones, and is standard on the current Android builds available on Pixel. Can we expect to see Recorder ported to PCs? 'I don't have any details for it being available outside of Pixel at present', said a Google spokesman.

Do I still need a DSLR?

Meanwhile, promotional material for the large-screen Redmi Note 10 Pro phone from Chinese company Xiaomi raised hopes that it might perhaps be a comparable game-changer replacement for DSLR cameras. I quote:

'Redmi Note 10 Pro ups the ante as one of the highest-resolution cameras for smartphones, making it the mid-range king in mobile photography. The phone's 108MP sensor with 9-in-1 binning technology and Dual native ISO combine to capture the finest details, provide a higher dynamic range and offer an array of photo editing possibilities. Thanks to the Night mode 2.0, powered by a RAW multi-frame algorithm, users can capture stunning visuals even in low-light settings.'

Seeking more – and more coherent – information, I contacted Xiaomi's appointed publicity people, Hill and Knowlton Strategies, writing: The Note 10 is promoted as having a 108MP camera sensor, but how crisp enlarged/telephoto shots look, in bright or dim light, will depend on how the 108MPixels are grouped/binned. Also, this will affect the file size and thus how many pictures the user can take before the internal storage is full. So can Xiaomi please clarify how the pixels are binned – in groups of how many – to get a good compromise between telephoto resolution, low-light sensitivity and file size? Does the user have any control over binning in any Settings menu?'

After a month and many reminders, mostly simply ignored by HKS, I had still received no meaningful answer. For the sake of completeness, I copied the unanswered question to HKS CEO Simon Whitehead with a note suggesting 'it might be worth the price of a stamp to wonder if this (failure to respond) interests you'.

So far there's been no response. If I ever get any useful answers, then I will pass them on, but I am not holding my breath.

tekkiepix pic of the month – 3D TV

Michael Rodd hosting ITV contractor Television South's 1982 3D-TV experiment.

3D is one of those inventions that keep on coming back. In 1982, TVS, the ITV station then serving Southern England, promised full-colour TV in 3D from a secret new process. *TV Times* magazine distributed 8 million pairs of 3D glasses, while high street retailers offered another 5 million pairs for sale.

The secret system was based on the age-old anaglyph idea, with coloured fringes added to overlapping left and right eye images. Viewers with the special spectacles, which put a red filter over one eye and blue over the other, got an illusion of depth and a degree of colour. But the millions of other viewers who watched the cowboy feature film *Fort Ti*, which TVS broadcast at peak hours, saw drunken double images. They jammed the switchboards of both TVS and the Independent Broadcasting Authority (then responsible for commercial broadcasting) with complaints. Since the *Fort Ti* debacle, the broadcast authorities in the UK have allowed only very short 3D test transmissions.

In 1988 Aspex claimed to offer the best of all worlds, 3D for people who wear spectacles, and perfectly good, even improved, pictures for those who do not. The Aspex camera put a colour fringe around any object on screen that was moving. When a viewer wore a red filter over one eye and cyan over the other, there was an illusion of depth when the image on screen was mobile. With stationary objects, the 3D effect disappeared. Viewers without spectacles saw a normal picture when objects on screen were stationary but colour fringing where there was movement.

In mid-1990, the Delta Group in London promised a new approach. Delta said its Deep Vision system was, 'a digital process which especially encodes the image – when the image is viewed through a television, or in a cinema, equipped with a digital decoder, the viewer experiences 3D…Deep Vision activates the brain's powers of depth perception'.

They offered a demo in a darkened room where a domestic TV set, roped off some 25 feet away, screened clips from *Ben Hur* and *Casablanca*.

Those who dared to step over the rope saw a flat plate, with vertical prism stripes, hung over the screen. So each eye saw mainly one of two laterally shifted images. But even on the distant screen, the pictures looked blurred and of poor definition. There was a slight sensation of depth, mainly on moving objects, psychologically enhanced by the inventor's enthusiastic commentary.

'Look how good it is. You can really feel it's coming towards you', the demonstrator encouraged, explaining that the screen grid would be soon improved and its effect assisted by electronics.

A couple of months later, Delta gave a similar demonstration at Selfridges store in London. 'Don't look at the quality of the picture, just look at the depth', shoppers were advised as they watched a domestic TV set from the same decidedly non-domestic viewing distance. Decoders would be on sale by Christmas, Delta promised. But Christmas came and went with no sign of Deep Vision.

Over the years, several companies have shown TV sets that claim to give 3D without the need to wear glasses. But they are not there yet.

More technology stories and images at:
https://tekkiepix.com/stories

Practical Electronics is delighted to be able to help promote Barry Fox's project to preserve the visual history of pre-Internet electronics.

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Rotten luck

Techno Talk

Mark Nelson

Bad news: disc rot is back… with a vengeance. We thought optical media would last forever, but it turns out there is a potentially catastrophic problem with DVDs – and at this stage we're not even certain how widespread the problem may be.

Are you one of those cool dudes who has ditched your collection of DVDs and instead opted to stream your favourite movies and TV programmes from the 'Net? Good on you! You made a wise choice and can now save fifteen minutes of your precious time. Skip the rest of this article and turn the page!

Alternatively, you may have a carefully curated collection of DVDs, probably including some impossibly hard-to-find titles. If so, prepare to feel sick. Some of your *deeveedees* may be starting to self-destruct. To make things perfectly clear, these reports are about 'proper' factory-pressed DVDs — the ones with shiny, silvery backs. We are not discussing those recordable DVDs with backs of purple or some other strange hue. So what's going wrong with these discs that we all thought were well-nigh indestructible?

Potentially catastrophic

Perhaps that's an exaggeration in global terms, but it could be bad news economically for the companies who produce and sell DVDs, especially if they are forced to compensate the customers who paid good money for them. Recent rumblings from movie buffs in the US complain of pressed commercial discs failing to play properly (or at all). Named most frequently are Warner Bros and Fox discs of Hollywood movies manufactured before 2010. This covers thousands of films released on DVD during that period.

My informant wites: 'Since most of the complaints do not originate in the UK and these faults might conceivably be the result of extreme heat or humidity, I ignored these stories as not relevant to the UK. Yesterday, I deliberately took a mint, unplayed DVD from a boxed set from that period, which was noted by collectors as one of those affected. It stuck halfway through. So I tried another disc from a different boxed set, with a similar result. I tried different drives and players. I also cleaned the discs, but they were both still faulty. Each time irrecuperable read I/O errors were reported. This raises several questions about the longevity of optical discs, especially as there is no apparent consistency of the fault. However, the numerous 2006 to 2008-era DVDs that fail read-error tests usually have one or more of the following numbers etched on the underside inner ring: IFPI L906, IFPI L907 or IFPI L908.'

This could generate reputational damage, as the general robustness of optical discs has led to a false sense of purchaser security. If this new 'DVD disease' affects potentially every DVD ever produced, the DVD and Blu-Ray industry is in deep trouble. The sincere hope currently is that the discs affected are only those made at specific manufacturing plants or else during a few years of production. It would indeed be disastrous if we should now have to consider the DVD format potentially unstable.

What to do now?

One American collector reports finding around 200 affected in this way, and many other users have discovered dodgy discs. If you have any recording of great importance or a DVD that you treasure above everything, should you back these up? If so, on which format? Hard drive? Or use one of those hideously expensive archival-grade DVDs that is claimed to last for 100 years? The real horror of it is we just don't know.

At this stage there appears to be no concerted industry response to the problem, with movie studios acting inconsistently. Some companies have replaced defective DVDs, while others are refusing to provide replacements outside of the normal warranty period. It may be that consumer associations will launch class actions, forcing the producers to issue replacements. There is a legal precedent for this in Britain, as this is what happened when large quantities of faulty CDs had to be replaced. Mind you, in some cases the firm that released the films originally may no longer have the rights to re-press the DVDs if those rights have changed hands.

Now for the techie stuff

So, what exactly is 'disc rot'? It's the name given generically to a number of mechanisms by which CDs, DVDs laser discs and even Blu-Rays tend to self-destruct. All of these discs are optical media in which binary data is recorded in the form of 'pits' (minute depressions) and 'lands' (flat surfaces) that represent the digital values of one and zero. The rot occurs as a result of physical or chemical deterioration that causes the recorded data to become unreadable. Potential causes of 'rot' include oxidation of the reflective layer, physical scuffing or abrasion, reactions with contaminants (such as spirit marker pens), fading caused by exposure to ultraviolet light and debonding of the adhesive used to adhere the layers of the disc together. The marketing claim made originally that optical discs were indestructible was pure fantasy – or lies – take your pick!

The rot causing the current flood of complaints is reportedly confined to double-layer pressings of two companies' releases from 2006 through to 2008, in which the double-layer transition point deteriorates. DVDs produced prior or subsequent to this time period do not (generally) show read errors. It appears that a specific manufacturing plant used faulty/defective double-layer DVD materials. Single-layer pressings of this era do not seem to be affected. Read errors occur usually (and specifically) at the double-layer transition break. Sometimes, this renders the DVD unloadable from the very start. Other times, the DVD will load and the film will play fine all the way through. However, the 'Special Features' (which can be selected from the menu) will not play. When the Special Features do decide to play, then the film or main feature will start fine and then freeze about 1 hour 40 minutes in. This may possibly depend upon the specific location of the dual-layer defect (ie, whether it occurs in the first layer or the second). Many boxed sets are affected, particularly those from 2006-2008 with slim cases, though quite a few individual DVD releases are also problematic.

Sorry to be a gloomster again. I'll try to find something more cheerful to write about next time.

Win a Microchip MPLAB ICD 4 In-Circuit Debugger

Practical Electronics is offering its readers the chance to win a Microchip MPLAB ICD 4 In-Circuit Debugger (DV164045) – and even if you don't win, receive a 20%-off voucher, plus free shipping for one of these products.

The new MPLAB ICD 4 introduces a faster processor and increased RAM to deliver up to twice the speed of ICD 3 for in-circuit debugging of PIC microcontrollers and dsPIC digital signal controllers. The MPLAB ICD 4 also introduces a wider target voltage range and an optional 1A of power via an external power supply.

For maximum flexibility, MPLAB ICD 4 features a selectable pull-up/pull-down option to the target interface and programmable adjustment of debugging speed for greater productivity. The MPLAB ICD 4's significant improvement in speed is accomplished through a 32-bit MCU running at 300MHz. Faster processing, together with an increased buffer memory of 2MB, results in a product that is up to twice as fast as its predecessor.

Worth $298.99 (approx £216.50) each

Microchip's MPLAB ICD 4 is easy to use and supports many PIC microcontrollers and dsPIC digital signal controllers in Microchip's portfolio through the MPLAB X Integrated Development Environment (IDE). This simplifies the design process for customers when they choose to migrate from one PIC MCU to another to meet the needs of their application

The MPLAB ICD 4 connects to a PC using a high-speed USB 2.0 interface and is connected to the target with a debugging connector which is also compatible with the MPLAB ICD 3 or MPLAB REAL ICE In-Circuit Emulator systems. The MPLAB ICD 4 also works with JTAG interfaces.

Faster and more flexible real-time in-circuit debugging:
- Supports many PIC microcontrollers and dsPIC DSCs
- x2 faster than ICD 3
- Reduced wait time improves debugging productivity
- Simplifies migration between PIC MCUs

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Microchip MPLAB ICD 4 In-Circuit Debugger

How to enter

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https://page.microchip.com/PE-ICD4.html

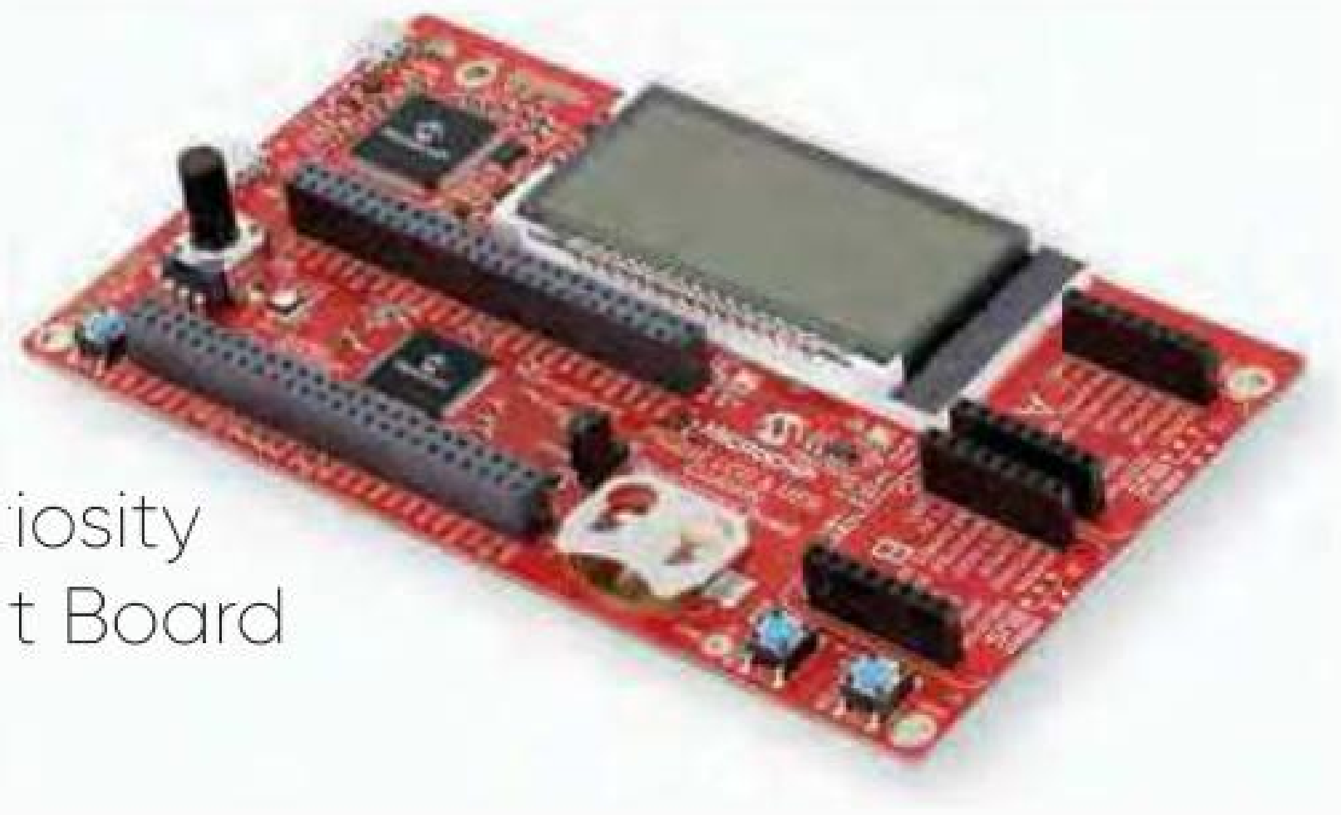
Closing date

The closing date for this offer is 30 June 2021.

March 2021 winner

John Waker

He won a Microchip PIC24F LCD and USB Curiosity Development Board



Net Work

Alan Winstanley

This month, *Net Work* looks at some important backroom changes in the way eBay pays and charges its users; plus the latest news from space and upmarket electric vehicles.

Last month, I mentioned some changes that eBay has made following its lengthy divorce from PayPal. It's the most radical shake-up in many years and it affects all eBay sellers who used PayPal for receiving payments. eBay has grabbed the steering wheel and created a payment chain called 'Managed Payments', which sees sellers waiting several business days or more before funds arrive in their current (checking) account. eBay has coined the buzzword 'Seller Onboarding' to describe the compulsory migration of private and business sellers to this new regime.

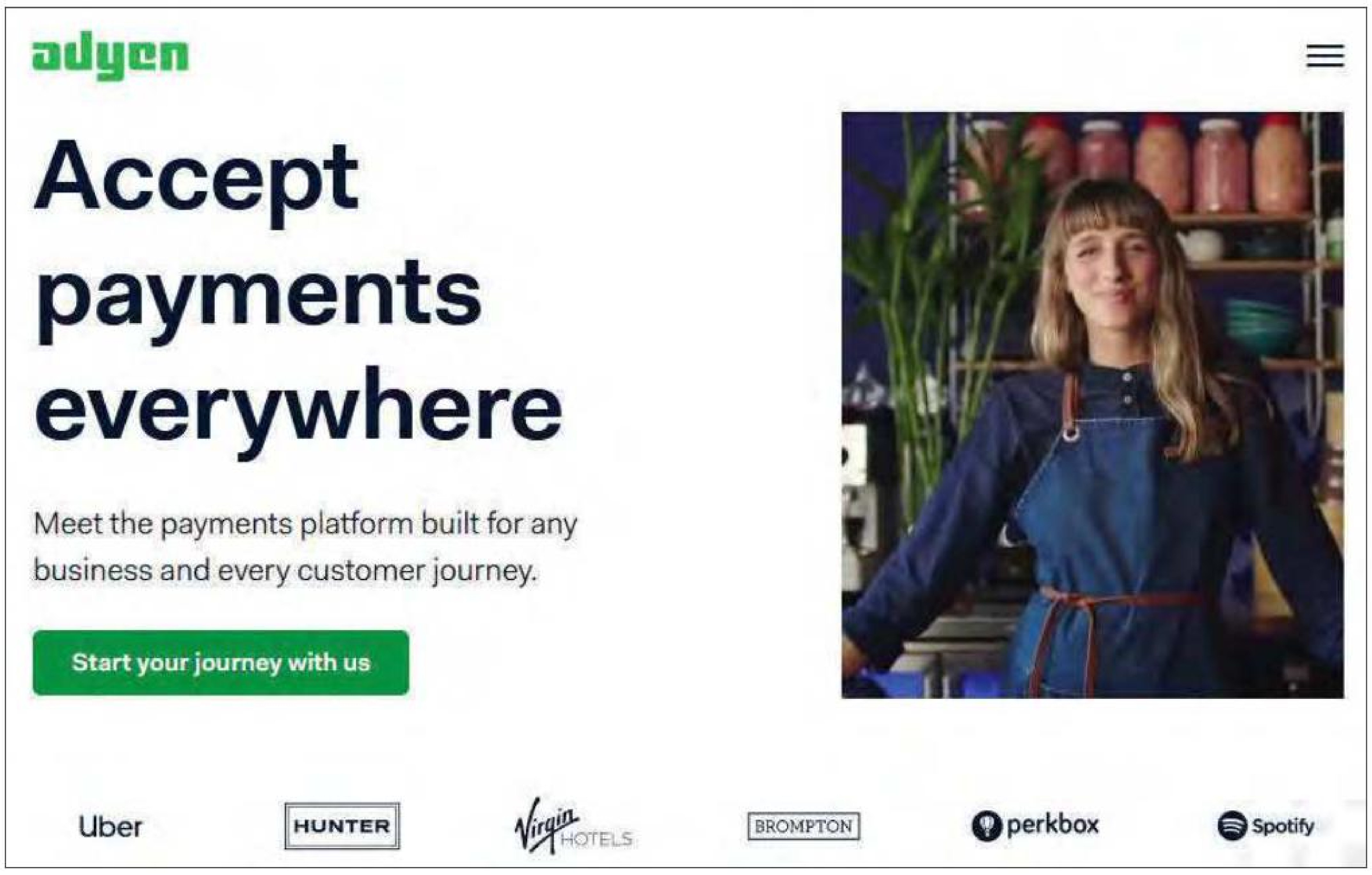
eBay changes – for whose benefit?

We know that 'Caveat Emptor' means 'Buyer Beware,' but what about sellers? At one time it was simple enough for private sellers to conveniently sell off unwanted surplus items, or maybe sell bulky furniture in 'Local eBay'. Countless small kitchen-table businesses and cottage industries sprang up on eBay, selling their low-cost wares; and of course more expensive items such as cars, cameras, caravans and computers costing thousands are offered as well.

First and foremost, eBay knows that without buyers, it wouldn't exist, so its Buyer Protection Program goes to great lengths to reassure buyers about their safety and security (visit: **http://bit.ly/pe-jul21-ebay1**). As eBay sellers know, if a buyer checked out promptly using PayPal, funds could arrive in the seller's PayPal account almost straight away (minus a 2.9% + 30p PayPal fee). The UK's Faster Payments Scheme made it quick and easy to transfer cash instantly into a current account, which was a valuable lifeline for small traders and private individuals. Residual PayPal balances could pay for couriers such as Parcelforce or My Hermes, or to buy other stuff. Incidentally, some useful tips and fraud prevention advice for consumers are worth reading at: **www.fasterpayments.org.uk**

Farewell to PayPal

After cutting ties with PayPal, eBay now steers payments through the Dutch-based payment processor Adyen NV (**www.adyen.com**). Many consumers might not have heard of Adyen (Surinamese for 'Start over again', apparently), but they provide high-end payment platforms, physical and virtual payment cards and back-office systems for many well-known international brands. However, it now takes typically two business days or more before eBay sellers receive cash into their current account. Gone too is eBay's monthly direct debit in arrears, in settlement of their fees; eBay now deducts their fees immediately before Adyen remits the balance.



adyen

Accept payments everywhere

Meet the payments platform built for any business and every customer journey.

Start your journey with us

Adyen is a high-end payment platform used by major brands. It's now handling eBay sellers' payments instead of Paypal.

As eBay tells its private sellers about Managed Payments: 'Fees and expenses will be deducted before you get paid, and the remainder of your eBay earnings will go directly to your bank account, not your PayPal account.... [This means] No more PayPal fees.' What's not to like? I recently purchased a few items on eBay without a hitch, using PayPal as normal, but delivery took a day or two longer than expected. To test eBay's new sales regime, I listed a private item for sale timed to finish a week later, on a Friday afternoon. Sure enough, it sold and eBay confirmed it was 'awaiting payment'; two days later (Sunday night) eBay advised that 'the buyer has confirmed the payment' and told me to post the item off. Still no sign of funds arriving of course, but not to worry, as eBay re-assured me that payouts are 'initiated within two working days of order confirmation'. The proceeds (less eBay fees) arrived in my bank a couple of days after that, making four calendar days in total including the weekend. Bank holidays could extend the delay even more.

eBay claims this timeframe is on a par with credit card transactions, as seen in business and commerce. That's true, but many private sellers trying to sell humble bits and pieces on eBay won't be impressed. There's another catch: although sellers now 'avoid PayPal fees' as eBay claims, eBay UK has increased its private sale fees from 10% to 12.8% plus 30 pence per item, plus a similar fee on postage charges. (In fairness, eBay's fees on postages arose after some sellers gamed the system by selling items at low cost (means, low eBay fees) but hiked the postage prices instead, because P&P was free of eBay fees.) Consequently, eBay's new fees for private sellers broadly match the total fees that eBay would have earned if they'd still owned PayPal anyway. eBay is, however, so far maintaining its free listings offer for private sellers which allows them to list up to 1,000 items free of initial fees.

Sellers have a choice of either signing up (sorry, 'onboarding') or quitting using the platform. That's just how it is. Quite a few small-time sellers and individuals may be deterred from using eBay, especially when you consider the latest T&Cs, discussed next.

A complicated business

eBay's new 'Seller Hub' has also come in for fierce criticism from many sellers. Instead of compact, at-a-glance web summaries (or 'Classic View') of transactions and their status, bloated screens full of flat-tiled drag n' drop sections now provide an in-depth analytical view of items on sale: it's mostly irrelevant for small one-off or occasional sellers. It can be customised and eBay says the new hub enables them to utilise modern data processing systems. Just as Google and Amazon over-analyse data for the benefit of high-end users with PhDs in computer science, eBay is doing the same. I gave up on it: for now, sellers can opt out of the Seller Hub but will be nagged into trying it again. The system for actually listing items for sale in the first place has also become mind-bogglingly complex, with screens full of myriad options and tick boxes now evident: selling on eBay has become a jolly complicated process.

eBay's new payment terms are spelt out at **http://bit.ly/pe-jul21-ebay2** in turgid legalese that runs to 16 pages. The terms throw up some contentious points, particularly when things go wrong (for the seller). Sellers have to sign up for eBay's 'Money Back Guarantee,' but this is vulnerable to customer abuse, such as buyers merely changing their mind and falsely claiming an item was 'not as described' and demanding a refund, sometimes many months later. The seller must then re-collect the goods at their own expense or risk losing them (and their money) altogether. eBay's 'Seller Protection' policy claims to cover sellers against that sort of abuse and negative feedback, as long as sellers 'create good buying experiences', so sellers must ensure their services tick all of eBay's boxes to begin with, to avoid the risk of losing their goods and money due to bogus claims made by buyers. The policy is at: **https://tinyurl.com/7t7xbb6m**

Judging by forum complaints, some sellers just write problems off to experience as eBay will often side with the buyer anyway, some say, but it's worth remembering that if things goes wrong, eBay ultimately gives itself permission to reimburse buyers and claw this back from your bank account directly, without so much as blinking. eBay in any case makes themselves the final arbiter in any disputes – just as PayPal was – and any disputes that do somehow make it through a long-winded arbitration do so at the seller's expense, at least initially.

Chilling out: OneWeb and Hughes will test LEO satcoms to connect Arctic regions for the US Air Force. Shown here, the OneWeb gateway in Svalbard, Norway, capable of 10,000 handoffs per second, is one of the gateways developed by Hughes that will orchestrate handover and tracking of gigabits of data for NORTHCOM. Credit: OneWeb/Kongsberg Satellite Services (KSAT).

Worst case, eBay also gives themselves the right to lock accounts or freeze funds, which can have devastating consequences for innocent sellers. Some businesses cited crippling problems they suffered due to eBay withholding funds (double the amount necessary) as security to cover a customer's refund. It's true that many UK businesses face similar draconian terms and risks from ordinary credit card processing, including onerous PCI DSS conditions. In Britain, start-ups with no trading history can find it very difficult to open a credit card merchant account unless they pay a hefty security deposit up front, such is the risk from fraud and money laundering that the credit card sector is grappling with. Services such as Zettle (**zettle.com**, owned by PayPal) or Square (**https://squareup.com**) may be the only ways some traders can take debit or credit cards.

Buyers using eBay won't notice much difference, but eBay's changes are here to stay, and sellers have no option but to 'onboard' them. It's become more complex and time-consuming to list just a few bits and bobs on eBay. It's worth sellers checking the Managed Payments terms and Seller Protection Policy closely and weighing up the risks, especially when valuable private sales are concerned, before deciding whether eBay is still worth your time and effort. Remember the phrase, *Caveat Venditor* – let the seller beware!

OneWeb for all

It's been a busy month, especially if you're in the business of launching satellites or people into space. As *Net Work* readers know, all eyes are on the constellations of LEO (low-earth orbit) satellites currently being assembled by SpaceX, OneWeb and (eventually) Amazon's Kuiper. SpaceX continues to enjoy remarkable success with its reusable boosters that return to earth (or land on a ship-based platform) with pinpoint accuracy, to be recovered and made ready for its next mission. Some SpaceX vehicles will soon have been re-used ten times and about 1,400 satellites are gradually getting in position to span the globe, with the possibility of tens of thousands more (literally) of them being lobbed up in the future. Where available, you can order or pre-order Starlink satellite-based Internet at: **www.starlink.com**

SpaceX also celebrated a successful launch and safe return of its stubby Starship vehicle SN-15 following a high-altitude flight test. After launching, it 'bellyflops' through the atmosphere before righting itself for a vertical landing, see: **https://youtu.be/z9eoubnO-pE**

OneWeb progress

Six months after emerging successfully from Chapter 11 bankruptcy protection after being bailed out by the UK Government and India's Bharti Global, London-based OneWeb (or WorldVu Satellites Limited as they are properly known) is focussed on opening its own satellite-based broadband network before the end of the year, offering services to commercial, marine, aviation and governmental sectors. In April Arianespace launched 36 more OneWeb satellites from the Vostochny Cosmodrome in the Russian Federation, making 182 satellites so far, with 466 of OneWeb's so-called 'First Generation' satellites still to go. This mission brings OneWeb a step closer to achieving its 'Five to 50' ambition, they say, offering coverage to areas 50° latitude and above, by the middle of this year. Several 3.5-metre ground-based antennae would be grouped together at gateway sites to allow access to multiple OneWeb satellites simultaneously.

Virgin Galactic's latest space vehicle called 'Imagine' starts ground trials this year. The firm hopes to offer up to 400 flights a year to 'private astronauts'.

OneWeb is also expected to partner with telecoms providers and provide them with a 'backbone' for a satcoms service.

There's more encouraging news from OneWeb: global satellite operator Eutelsat is investing some $550m and taking a 24% stake in the network, subject to regulatory approval. OneWeb's ambitions include a satellite constellation of just over 6,000 so-called 'Phase 2' satellites, a significant reduction from the nearly 48,000 units originally proposed. According to OneWeb's FCC filings, their Phase 2 satellites will provide broadband internet to users anywhere on Earth, flying at a much lower orbit than geostationary orbit (GSO) satellites with a latency of less than 50ms, which is comparable to terrestrial networks, they state.

The US's Hughes Network Systems (**www.hughes.com**) is also a OneWeb core investor; in May Hughes and OneWeb announced they had been selected by the US Air Force Research Lab to trial LEO satcoms services to connect the Arctic region to sites located around the globe.

The field of satellite-based navigation (collectively called GNSS, or Global Navigation Satellite System) may see OneWeb becoming involved with building a new network for the UK. Readers might recall how, following Brexit, Britain was unceremoniously ejected from the EU's own Galileo satnav program, despite the UK's substantial investment in its development. Galileo is intended to be independent of the USA's GPS system and the UK has since been denied access to high-accuracy Galileo signals used by the military, for example. Last year, the UK Government announced that its Space-Based Positioning Navigation and Timing Programme (SBPP) would examine alternative ways of delivering these critical 'PNT' services to United Kingdom infrastructure. It is becoming ever more imperative that a newly independent UK bolsters and safeguards such systems to meet the new challenges that are fast heading our way.

Out of interest, at one time an alternative to GNSS was LORAN (LOng RAnge Navigation), a hyperbolic radio navigation system with roots originating in the Second World War and Britain's GEE ('G' for grid) aircraft direction-finding system. LORAN gradually became obsolete, but modern electronics might one day see Enhanced LORAN becoming available as an Alternative Positioning Navigation and Timing (APNT) system that is ground-based and highly resilient. Military history or ex-Air Force readers might enjoy some WW2 background to GEE and LORAN in the PDF at: **http://bit.ly/pe-jul21-gelo**

Space Hopper

Amazon's proposed Kuiper network has received approval to launch about 3,200 satellites delivering broadband services, but the service is 'under construction' and Kuiper is arriving late to the show. Scanning through some complex FCC rulings reveals that not everything has gone in Kuiper's favour: a deadline has been set for Amazon's offshoot to launch 50% of their proposed network by mid 2026 and the rest by 2029. Kuiper must also post a surety bond for an undisclosed amount, which will be forfeited if the FCC's targets are not met, according to the ruling.

Meanwhile, Amazon's founder, Jeff Bezos, is focussing his Blue Origin rocket venture on space tourism using his 'New Shepard' (NS) module (named after Alan Shepard, the first American to fly into space, almost 60 years ago to the day). Last covered in *Net Work*, March 2020, Blue Origin's VTOL vehicle will offer tourists a straight hop up into sub-orbit and down again, and the first excursion is already planned for 20 July after a succession of tests flights. The booster stage lands vertically, SpaceX-style, while the passenger module parachutes to Earth separately. You can observe the latest test flight, callsign NS-15, at: **https://youtu.be/domwsgorRW0**

If Blue Origin's rocket launches and bumpy landings aren't for you, then waiting in the wings, so to speak, is Sir Richard Branson's rival space agency Virgin Galactic, 'the world's first commercial spaceline', which has now completed its first Spaceship III plane or 'VSS' (Virgin Spaceship) called 'Imagine'. The firm faces a number of funding and legal challenges, but their latest mirror-finish space vehicle begins ground testing this year. Spaceplanes will be slung underneath a 'flying catamaran' carrier plane before being released at 50,000 feet, when the rocket-propelled spaceplane shoots upwards into space, experiencing zero G for a few minutes before returning to land on a runway. A small fleet of Virgin Galactic's space planes hope to make up to 400 flights taking 'private astronauts' from its spaceports into space every year, they say. I got truly dizzy on my PC trying to navigate their website (**www.virgingalactic.com**) searching for more information, but there's an early promo video at: **https://youtu.be/_XiKFf9vpG4**

Driving Polestar position

More exciting new electric vehicle (EV) brands are making the news: the Polestar marque has started to pop up discretely on British TV in the first shots of a brand-awareness campaign, but this low-profile marketing belies a high-quality premium EV waiting in the wings from a brand owned by Sweden's Volvo (and in turn, China's Geely). The Polestar 1 is a 2.0 litre petrol/hybrid limited-production car, but all eyes are on Polestar 2, a svelte EV saloon with various battery and powertrain options. It will cost from £39,900 to £45,900. The *BBC Top Gear Magazine* has named Polestar 2 the best all-rounder electric car for 2021, and the car has been acclaimed as 'Best of the Best' by Red Dot in the international design competition's hotly contested Product Design segment. As a sign of how the motor trade is diversifying, buyers will have to order exclusively online at **www.Polestar.com**, but should be able to see and test drive the Polestar 2 from September 2021 at one of more than 40 'Polestar Spaces' in ten countries, the company hopes. Coincidentally, just as I finished writing this paragraph, a Polestar 2 drove right past my window, and it is indeed a sleek and distinctive-looking machine.

At the other end of the motoring scale, many Brits will have fond memories of Austin J2 trucks and, later, Leyland DAF panel vans, the latter becoming 'LDV' whose vans were a common sight on British roads at one time. Admittedly, I wasn't aware that LDV became Russian-owned in 2006 and was ultimately killed off by the recession. Just as Britain's MG Cars was snapped up

Polestar 2: a high-quality premium EV with Volvo parentage, heading our way later this year.

by China's SAIC (see *Net Work*, December 2020), the same happened to LDV in 2010. Judging by some recent Facebook pop-up ads, marketing of SAIC's 'Maxus' brand of commercial vehicles is now under way in Britain, including, of course, two electric vans. See **https://saicmaxus.co.uk** for information.

Chinese EV brand Nio is set to start shipping EVs to Norway from September. Why Norway? The Scandinavian country favours electric vehicle ownership with subsidies and free parking, and more than 70% of all new vehicle sales in 2020 were EVs, according to Statista. Rival brand Xpeng has already started sales in Norway with 100 G3 SUVs, as reported in the March 2021 *Net Work*. These cars may well be heading our way.

And finally

The car industry, as well as other sectors, continues to grapple with a global shortage of semiconductor chips, caused by a perfect storm of a huge surge in demand for electronic gadgets during Covid-19 lockdowns, a winter freeze-up causing outages at the NXP semiconductor plant in Texas, followed by a fire at the Renesas Electronics chip foundry in Japan last March. The global chip shortages could last until 2023, says chip maker Infineon, as a number of big names brands including Samsung, Apple, and most major car brands are hit by shortages. The semiconductor industry is desperately trying to plug the gap by finding obsolete manufacturing tooling that use old, obsolete wafer sizes.

The boardroom row at Nominet, the UK domain name registry, rumbles on (see *Net Work*, May 2021) after discontented members forced an Extraordinary General Meeting in March to vote four controversial directors out of office. The remainder of the board then refused to appoint the members' preferred caretaker chairman, interpreted as a sign of the contempt that the organisation (still) holds for its smaller members, despite Nominet having stated that it 'acknowledges that members have made a clear statement with today's vote and will be working on a strategic change in direction.'

The Department for Digital, Culture, Media & Sport (DCMS) told me that they expect Nominet and its membership to, 'work together on shaping the future of the company... Nominet is a private company that manages the .UK domain space and its leadership is a matter for its members', said the DCMS. It provides an 'essential service' that must satisfy the Network and Information Systems Regulations 2018 (NIS) and the DCMS continues to engage with Nominet and other parties hoping to resolve the current governance problems. A second rebel EGM that could, if successful, boot out the remaining board is a possibility.

If you're following my trials of Internet-enabled home security cameras, I'm happy to report that the Reolink PTZ types (see *Net Work*, May 2021) continue to perform very well, with no particular problems experienced. The Reolink app responds well on a smartphone using 4G, which allows up to four cameras to be monitored and controlled remotely in a single app. They are available on Amazon.

Finally, next month's column marks 25 years of *Net Work*, which first appeared in the August 1996 issue to welcome the new-fangled Internet, explaining how to connect a PC to a 14.4k modem or how to install anti-virus software. Society has since fully embraced the web, and the Internet now plays an everyday and essential role in our lives. I always enjoy reading readers' comments and feedback and the *PE* team is delighted to hear from those who have stayed with us since those early days: thank you all. *Net Work* has moved on too, and tries to keep abreast of topical trends in areas that are likely to affect us either now or longer term.

I'd like to thank all readers for their continued support and interest in *Net Work* and, as always, remember that I can be reached by email to: **alan@epemag.net** – see you next month!

The author can be reached at:
alan@epemag.net

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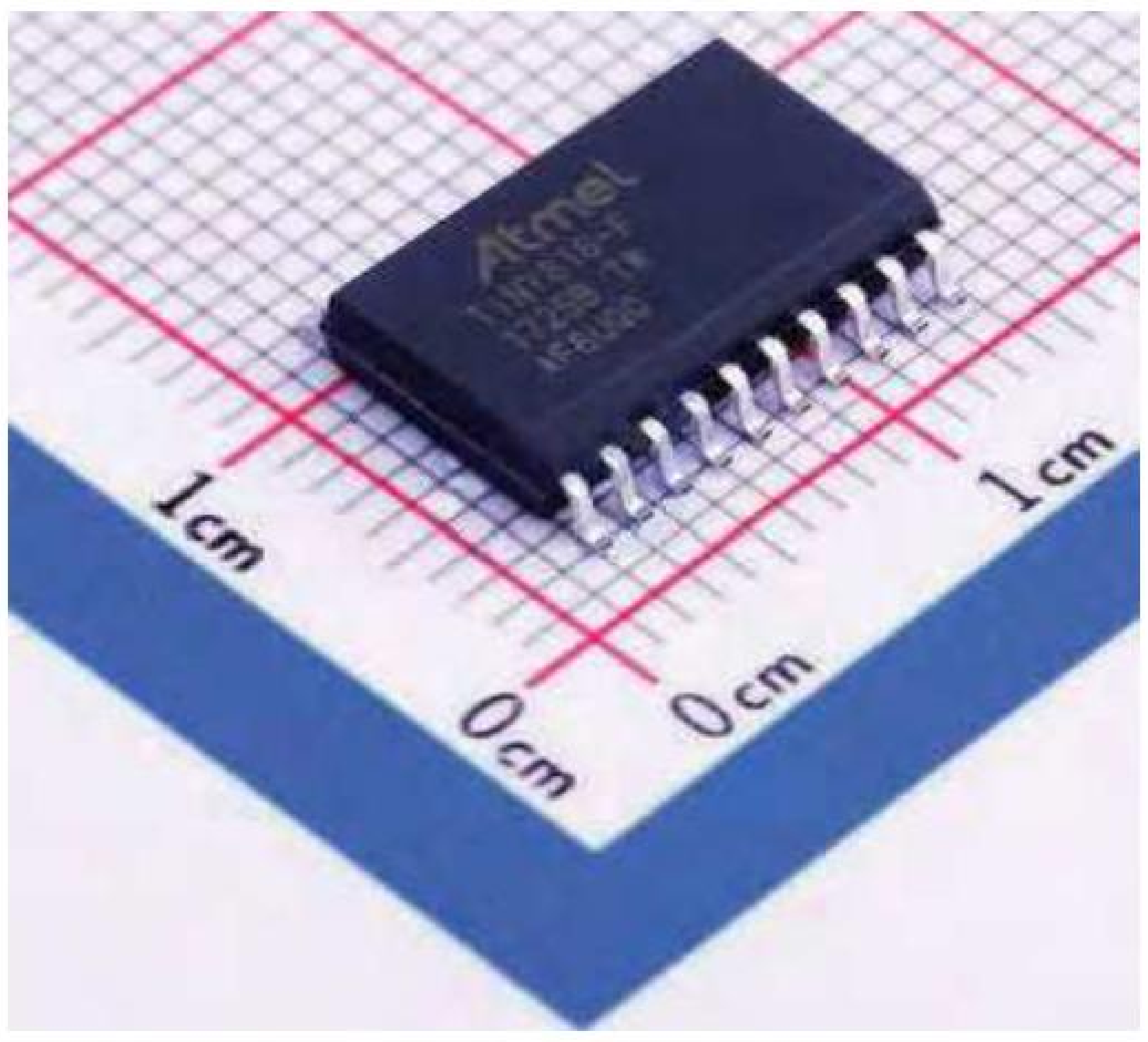


ATtiny816 Breakout and Development Board with Capacitive Touch

by Tim Blythman

After Microchip purchased their arch-rivals Atmel, good things started to happen. Now they are producing microcontrollers with some of the best features that we've come to expect from both companies. One such chip is the ATtiny816, and we're going to describe its features and show you how to use them.

We're fans of both the PIC and AVR families of microcontrollers for different reasons. So it's exciting to see the two worlds come together now that the companies have merged.

The new products are starting to combine the best features of the two families and the ATtiny816 is the one that we've chosen to use first. See the table below for a summary.

One of the (few) drawbacks of this chip is that, like so many ICs these days, it's only available in surface-mounting packages. But the 20-pin SOIC chip is not difficult to solder; however, you need some sort of 'break-out' board to experiment with it.

Breakout board

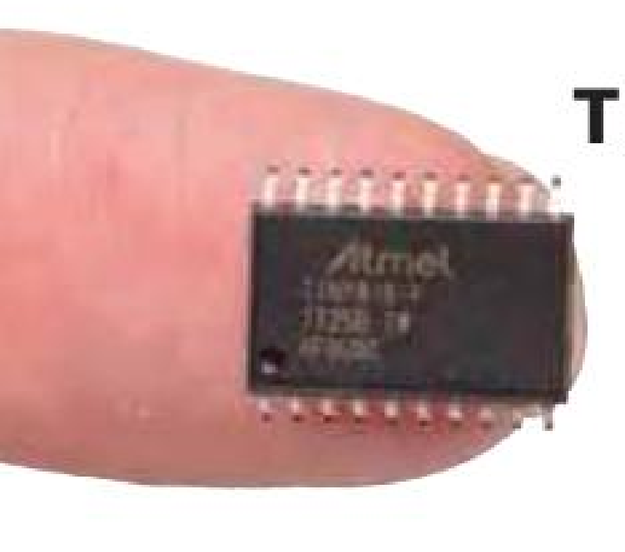
So we designed one! This board not only serves this purpose, but also contains some extra components to let you take advantage of its inbuilt capacitive touch sensing. Basically, you get four pushbuttons and/or a slider control essentially for free – there are no components to install. The PCB itself provides these controls!

We've also made provision on the board for five LEDs, because they're useful for debugging and indication purposes and they also look nice. Plus we've provided a space to mount a CP2102-based USB/serial adaptor and a USB socket to get power to the chip.

PICkit 4 programming

One of the thing that stops many people who are already into PICs from using AVRs is the need for a separate programmer. But now that Microchip and Atmel are one, they are starting to release AVR parts which can be programmed with the PICkit 4, and this is one of them. So if you already have the latest PICkit, you won't need any extra development tools. You can also use the same MPLAB X software that's used to develop code for PICs, too, as long as you have the latest version.

As well as showing you how to build and hook up the development board, this article will provide in-depth information on how to program it, including some sample software that will give you a good starting point.



The ATtiny816

When we first looked at the new ATtiny1607 chip's specifications they seemed great, but unfortunately it is only available in a 24-pin VQFN package, which would be too challenging for many readers.That's just the way things are going these days. But we decided to see if they had released any other, similar chips in larger packages.

After extensive searching, we discovered that the ATtiny816 has many of the same new features and is available in a 20-pin SOIC package. If you compare it to the ubiquitous ATmega328P used in the Arduino Uno, the ATtiny816 is really not that 'tiny'. It is at the lower end of the product range in terms of RAM and Flash space but overall, its hardware features are a big step up from the ATmega328.

The biggest change is the programming interface. The ATtiny816 is now programmed using the single-wire UPDI protocol, rather than the familiar four-wire SPI-compatible ICSP interface used on earlier ATmega and ATtiny chips. This is an evolution of the debugWire debugging interface.

You can see a sample UPDI waveform in Scope.1. It uses a half-duplex asynchronous serial protocol. Since this programming signal is fed to the device's reset pin, that maximises the number of available I/O pins for general purpose use.

Despite using a single pin, this programming scheme is fast compared to the old ICSP system. Admittedly, the ATtiny816 only has 8kB of Flash, but the delay between pressing the 'Program' button and seeing the results is just a few seconds.

We'll now run through some of the outstanding features of this chip, especially those that jumped out as being bigger than we expected for such a 'tiny' chip! For more detailed information, refer to the device's data sheet at: **http://ww1.microchip.com/downloads/en/DeviceDoc/40001913A.pdf**

ATtiny816 features

Number of pins	20
SRAM	512 bytes
Flash memory	8kB
EEPROM	128 bytes
Maximum clock freqrency	20MHz
ADC channels	12 x 10-bit
Event System channels	6
General Purpose I/O pins	18 (17 with UPDI enabled)
Timers	4
Communications	USART, SPI, TWI
DAC	1 x 8-bit

Do refer to the panel 'PIC vs AVR' at this stage, to get an idea of why we're excited about the meeting of the two worlds.

Analogue inputs

The 20-pin ATtiny816 has two power pins and seventeen I/O pins (eighteen if the programming function is disabled), of which 12 can be used as inputs for the 10-bit analogue-to-digital converter (ADC) module. That's twice as many possible ADC channels as the ATmega328 on an Arduino Uno board!

The ADC can also be used to sample the output of an internal temperature sensor and the DAC module output. The chip also features a true (non-PWM) 8-bit DAC. It only has a single channel and can only use pin 4 (PA6) for its output, but it can be updated at 350kHz.

It can be referenced to one of five internal reference voltages, but not, unfortunately, from the 5V rail. The highest reference voltage available is 4.34V. It also has an analogue comparator which can have its inputs connected to various I/O pins or the internal DAC's output.

Event System and Configurable Custom Logic

The Event System and Configurable Custom Logic (CCL) are designed to reduce the software and hardware overhead of designs using the ATtiny816.

The Event System runs independently of the core once set up, and is capable of triggering events when conditions are met, similarly to how interrupts are triggered. For example, a timer overflow can trigger the ADC module to start a conversion without a software interrupt handler being needed, removing the interrupt overhead and latency.

Another possible use is to provide gated timing, using an internal timer to count how long a condition (eg, an analogue comparator comparison) exists. CCL can be used to implement functions that would otherwise require external logic gates.

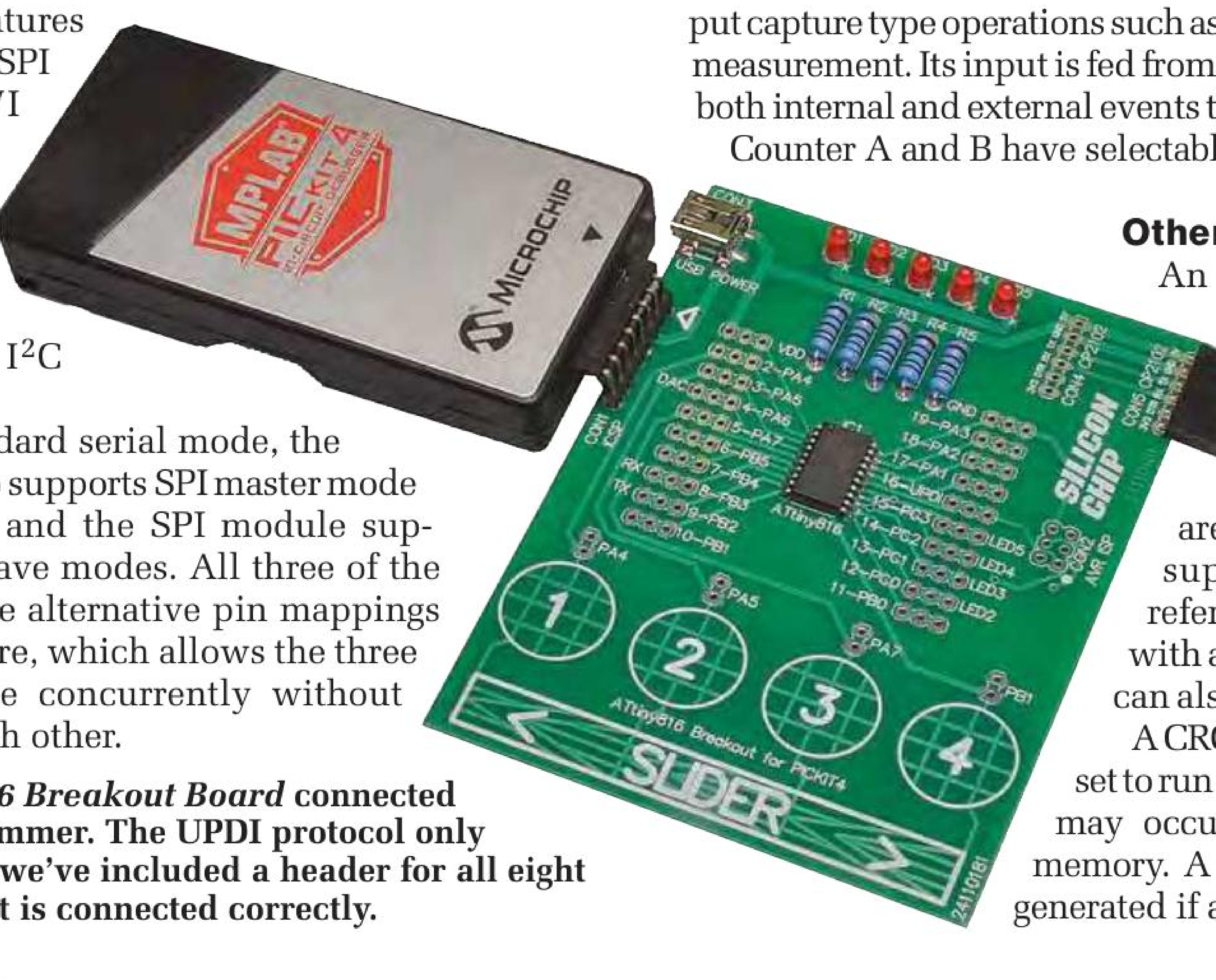
CCL involves two programmable look-up tables, each of which takes three inputs from either external pins or internal peripherals. A truth table determines what the output value should be based on the input states, allowing the implementation of basic or relatively complex logic.

A simple use case would be to mix the output from two timers to create a pulse-modulated tone. There is an Application Note describing the CCL and Event System that you can download at: **http://ww1.microchip.com/downloads/en/AppNotes/DS00002451B.pdf**

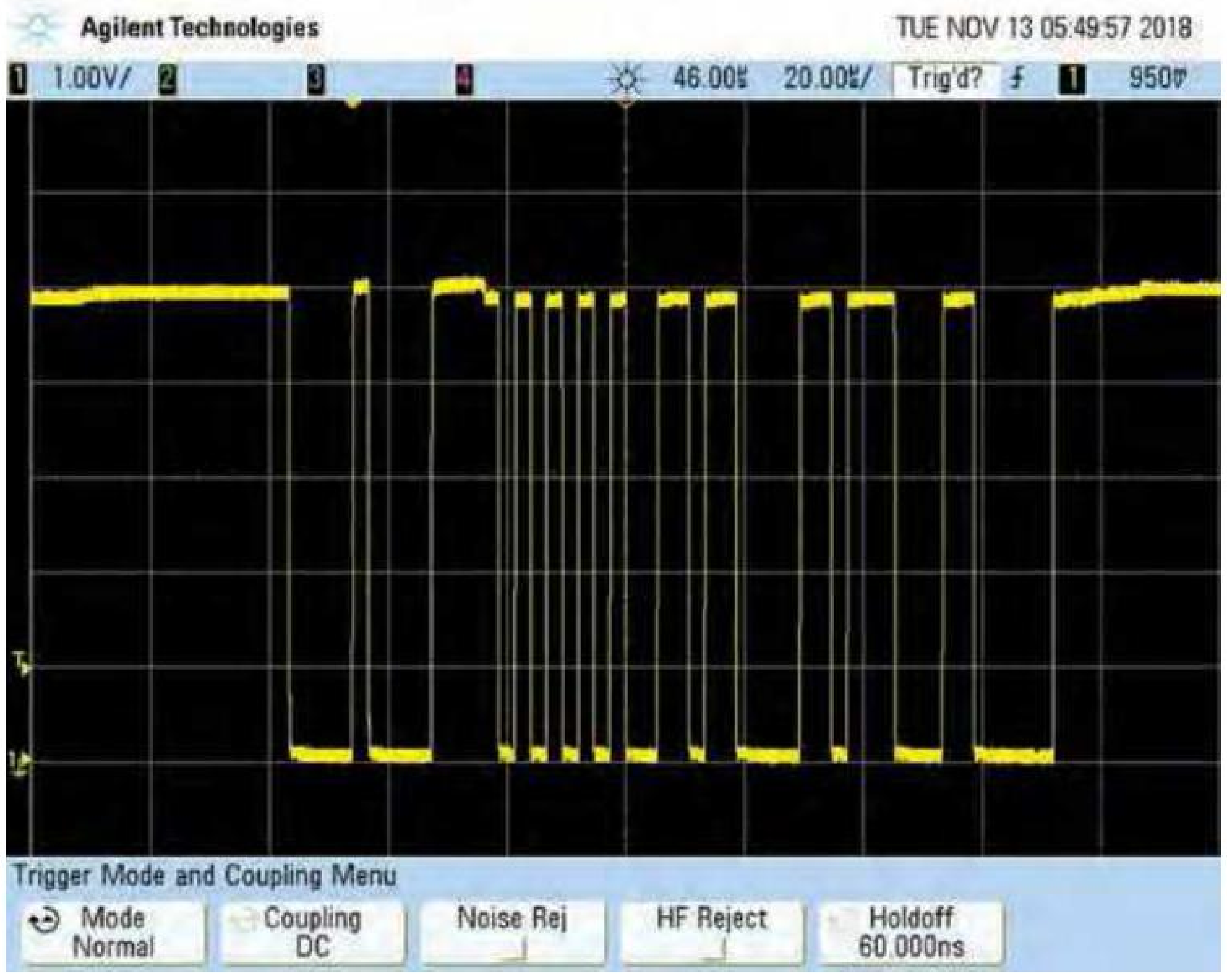
Communications

The ATtiny816 features a USART module, SPI module and TWI module. TWI stands for 'two-wire interface', and is a term often used to describe a bus compatible with I^{2}C and SMBus.

As well as a standard serial mode, the USART module also supports SPI master mode and RS-485 mode, and the SPI module supports master and slave modes. All three of the above modules have alternative pin mappings selectable in software, which allows the three modules to operate concurrently without interfering with each other.



Here's the *ATtiny816 Breakout Board* connected to a PICkit 4 programmer. The UPDI protocol only uses three pins, but we've included a header for all eight pins to ensure that it is connected correctly.



Scope.1: the UPDI one-wire programming signal used for this new generation of AVR chips. It appears to support reasonably fast re-programming of the chip. These new chips no longer support the old SPI-based in-circuit programming system used in older AVRs (eg, the ATmega328P used in the Arduino Uno). That frees up more pins for general purpose use.

Timers

The chip has three independent timer/counter modules as well as a 16-bit real-time clock (RTC) module. The RTC is suited for timekeeping tasks such as providing an application clock or generating periodic interrupts, and can be clocked from an internal low-power oscillator or an external watch crystal (for improved accuracy).

This frees up the other timer/counters for duties such as input capture, waveform generation, PWM and motor control.

The 12-bit Timer/Counter Type D (TCD) is specifically designed for motor control; it's able to provide programmable dead time and respond to events from the Event System. That would be useful to react to faults (either from a digital input or the analogue comparator), shutting down the motor control output under fault conditions without the delay of an interrupt service routine. 16-bit Timer/Counter A is suited for waveform generation and has three output compare channels.

It can be split into two 8-bit timer/counters, each with three output compare channels, giving the possibility of up to six waveforms being generated simultaneously. Timer/Counter B is also a 16-bit unit, and is more suited for input capture type operations such as frequency and pulse-width measurement. Its input is fed from the Event System, allowing both internal and external events to be measured. Both Timer/Counter A and B have selectable alternative output pins.

Other features

An internal voltage reference provides 0.55V, 1.1V, 1.5V, 2.5V and 4.34V references for use by the ADC, DAC and analogue comparator. These are independent of the actual supply voltage. The 4.34V reference would only be usable with a 4.5-5.5V supply. The ADC can also use VDD as its reference.

A CRC Flash memory scan can be set to run and detect any errors which may occur over time in the Flash memory. A non-maskable interrupt is generated if a CRC error is detected.

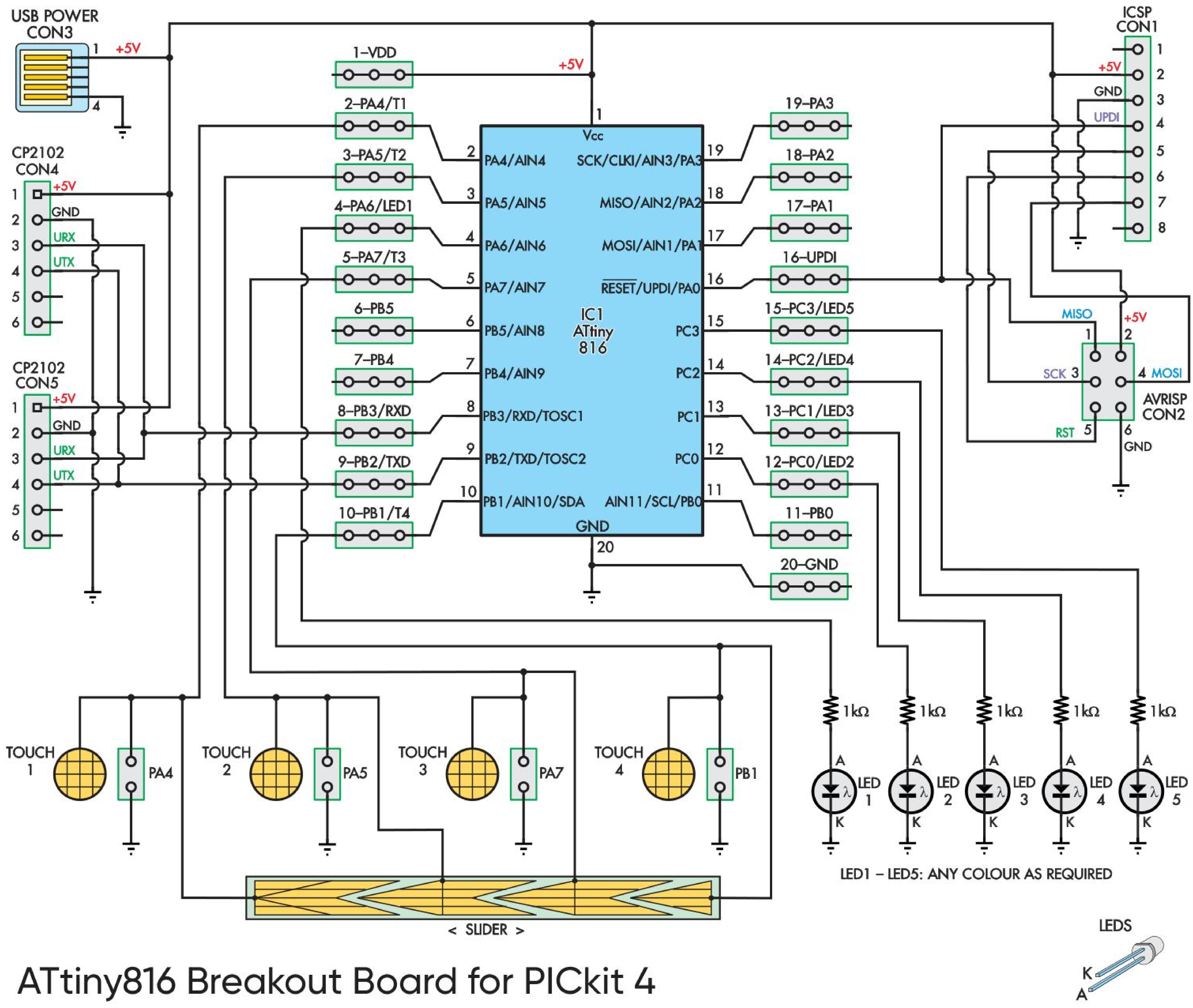

USB POWER CON3
+5V
CP2102 CON4
GND
URX
UTX
CP2102 CON5
1–VDD
2–PA4/T1
3–PA5/T2
4–PA6/LED1
5–PA7/T3
6–PB5
7–PB4
8–PB3/RXD
9–PB2/TXD
10–PB1/T4
Vcc
PA4/AIN4
PA5/AIN5
PA6/AIN6
PA7/AIN7
PB5/AIN8
PB4/AIN9
PB3/RXD/TOSC1
PB2/TXD/TOSC2
PB1/AIN10/SDA
GND
IC1 ATtiny 816
SCK/CLKI/AIN3/PA3
MISO/AIN2/PA2
MOSI/AIN1/PA1
RESET/UPDI/PA0
PC3
PC2
PC1
PC0
AIN11/SCL/PB0
19–PA3
18–PA2
17–PA1
16–UPDI
15–PC3/LED5
14–PC2/LED4
13–PC1/LED3
12–PC0/LED2
11–PB0
20–GND
ICSP CON1
UPDI
MISO
MOSI
SCK
RST
AVRISP CON2
1kΩ
LED 1
LED 2
LED 3
LED 4
LED 5
A
K
LED1 – LED5: ANY COLOUR AS REQUIRED
TOUCH 1
TOUCH 2
TOUCH 3
TOUCH 4
PA4
PA5
PA7
PB1
< SLIDER >
LEDS
ATtiny816 Breakout Board for PICkit 4

Fig.1: each pin of the chip is connected to a 3-pin header to make off-board connections easy. A programming header (CON1) is provided, along with a USB power input (CON3) and headers for a USB/serial adaptor (CON4/CON5). Five LEDs are also included for debugging and feedback, plus the four capacitive buttons and slider.

Peripheral Touch Controller

Details on this module in the data sheet are fairly scant. The data sheet states that 'the user must use the Atmel Start QTouch Configurator to configure and link the QTouch Library firmware with the application software.'

According to comments in online forums, the QTouch Library firmware can use up to 7kB of the ATtiny816's 8kB of Flash, and this is backed up by the fact that, according to the datasheet, the PTC is only available on the 8kB ATtiny816 and not the 4kB ATtiny416.

That seems excessive, and we didn't like the idea of using the library code without fully understanding it. So, instead, we've written our own code to provide a basic touch interface using a similar technique. (See the Sidebar for more information about how the 'Shared Capacitance Touch Sensing' works, and how we implemented it).

We can't claim that our software has the sensitivity or features of the QTouch Library firmware. For example, the QTouch Library can calibrate itself, and even detect when the touch sensors may be affected by moisture. Our system can't do that. But it seems to work well despite this, and uses a much smaller proportion of the Flash memory.

Microchip has made an excellent guide to the design of capacitive touch PCB buttons, wheels and sliders. We found some great ideas for what sort of touch sensors can be created from nothing more than PCB traces. It's available at: **http://ww1.microchip.com/downloads/en/appnotes/doc10752.pdf**

The development board

The above is by no means a complete list of all of the features of the ATtiny816; just the ones that we thought were most notable.

So that you can try out some of these features and incorporate one of these chips in a 'breadboard' type set-up, we have designed a development/break-out board which allows you to program an ATtiny816 with a PICkit 4 and connect it up to external circuitry.

The circuit diagram for this board is shown in Fig.1. Each of the 20 pins on the chip (IC1) is broken out to three separate header pins, to make connections to external circuitry easier.

There are five onboard LEDs, LED1-5, in case you need them. These light up when the following outputs go high: PA6 (pin 4), PC0 (pin 12), PC1 (pin 13), PC2 (pin 14) and PC3 (pin 15) respectively.

Programming header CON1 has eight pins, to suit the PICkit 4 (the PICkit 3 only had six, and generally didn't use the sixth). Theoretically, you only need the 5V, GND and

UPDI connections to program the chip but the other pins are wired up for completeness.

USB connector CON3 is purely to provide a source of 5V power to run the board (and IC1) – note that the PICkit 4 is not (currently) capable of supplying power to the board while programming a chip in UPDI mode. CON4 and CON5 make it easy to add a USB serial interface, which could be useful for debugging. These connectors are wired up to IC1's default UART pins. If a CP2102 module is fitted, 5V power can come from this instead of CON3.

As described earlier, the PCB incorporates four touch pads and a slider at the bottom. The pads and slider are both connected to the same I/O pins to simplify the code. The pins used to sense the four buttons are PA4 (pin 2), PA5 (pin 3), PA7 (pin 5) and PB1 (pin 10) respectively.

An alternative use

One thing to note is the presence of CON2, which is the old-style six-pin programming header. This is not provided for programming IC1, as this chip does not support such a programming scheme. Rather, it is included so that you can potentially use this board as a way to program older AVR chips using a PICkit 4.

If you need to be able to do that, you can use this PCB and simply fit CON1 and CON2 – nothing else. You can then plug the PICkit 4 into CON1 and connect CON2 to your target device (eg, using a 6-wire IDC ribbon cable). It then simply acts as an adaptor between the two connector pinouts.

Construction

The PCB overlay for the development/breakout board is shown in Fig.2. Use this as a guide during construction.

We recommend that you fit the ATtiny816 (IC1) first. Start by applying some solder flux to its pads, then locate the IC with its pin 1 dot towards the top left, as per Fig.2. Tack solder one corner pin in place and check that all the other pins line up with their pads.

If not, carefully adjust the IC by re-heating the solder joint and gently nudging it until it is located correctly. Then, tack the pin in the opposite corner and carefully solder each pin.

Inspect the IC using a magnifier and remove any solder bridges using a dab of extra flux paste and some solder wick.

Next, we suggest that you fit USB power socket CON3. Again, start by applying some flux to the pads, including the five small pins and the four large mounting pads. Drop the part in place and move it around until the plastic locating pins drop into the holes on the PCB. Then check that the five small signal pins line up correctly with the pads and tack one of the large mounting pins in place.

Re-check the signal pin alignment, then solder the other three large mounting pins, followed by the five small signal pins, which are partially hidden under the socket body.

We have put slightly enlarged pads on the PCB to simplify soldering them. You should just need to touch the iron (with a bit of solder on the tip) to each pad and it will flow onto the pins.

Only the two outside pads at the back of the USB socket are needed, as this socket is only used for power. The other pins may be soldered for completeness, but you must ensure they are not bridged to any pins, as they may stop the upstream USB socket from working correctly. If you have managed to bridge the pads, then use flux paste and solder wick to remove the bridges.

Fit the resistors next, then the LEDs. Ensure that the cathode flat of each LED goes to the right (adjacent to the 'K' mark), and that the longer anode leg is to the left. Solder right-angle programming header CON1 in place next.

You should only fit one of CON4 or CON5. Fit a vertical male header for CON4 if you want to mount a CP2102 module on the board permanently. Fit a vertical female header for

Parts list – ATtiny816 development board

1 double-sided PCB coded 24110181, 99mm x 77m
  available from the PE PCB Service
1 CP2102 USB/Serial adaptor module
1 8-pin right-angle pin header (CON1)
1 2x3-pin header (CON2, optional)
1 mini type-B SMD USB socket (CON3)
1 6-pin header (CON4) ***OR***
1 6-way female pin socket (CON5)
20 3-way pin headers (may be snapped from two 40-pin
  headers)
4 2-pin headers (optional; for external touchpads)

Semiconductors
1 ATtiny816 8-bit microcontroller, wide SOIC-20 (IC1)
5 3mm LEDs, various colours (LED1-LED5)

Resistors (all 1/4W or 1/2W 1% or 5%)
5 1kΩ

PIC vs AVR

We should explain the pros and cons of AVR vs PICs, as the ATtiny816 combines many of the advantages of both architectures.

The main advantage that AVRs always had over 8-bit PICs was the use of a high-speed, high-efficiency RISC CPU core. It can process one instruction per clock and most AVRs can run with a clock up to 20MHz. So you could easily execute 20,000,000 instructions per second with a typical AVR chip.

On the other hand, most 8-bit PICs execute one instruction for every four clock cycles. So even though some of them can run with a clock speed up to 48MHz, that equates to the execution of just 12,000,000 instructions per second – barely half that of the AVRs.

Also, the AVR instruction set lends itself much better to compiler-generated code, so you generally get excellent results using the free avr-gcc 'C' compiler, whereas PIC compilers used to cost money (they still do if you want all their features) and usually are far less efficient, generating larger and slower code by comparison.

On the other hand, many PICs contain internal PLLs which allow them to run at maximum speed without an external crystal or resonator. By comparison, AVRs are generally more limited. They mostly lack PLLs, but they usually do have one or more internal resonators. However, these may not allow them to operate at full speed. For that, you generally do need extra external components.

Another advantage of PICs over AVRs is that they are programmed in one pass, with a single HEX file, whereas AVRs have a separate set of EEPROM 'fuses' which need to be programmed to access all the device's features. Not only is this a separate step, but getting it wrong can effectively 'brick' the chip.

And even if you get it right, you may have difficulty reprogramming the chip afterwards, as the programming interface was traditionally clocked based on the crystal and oscillator settings. So there is a bit of a 'chicken-and-egg' type problem programming many AVRs.

Finally, PICs were usually cheaper than similarly-specced AVRs, and often came with a much more full set of internal hardware peripherals. But that's all changing now that Microchip is starting to add their generous hardware to AVR cores.

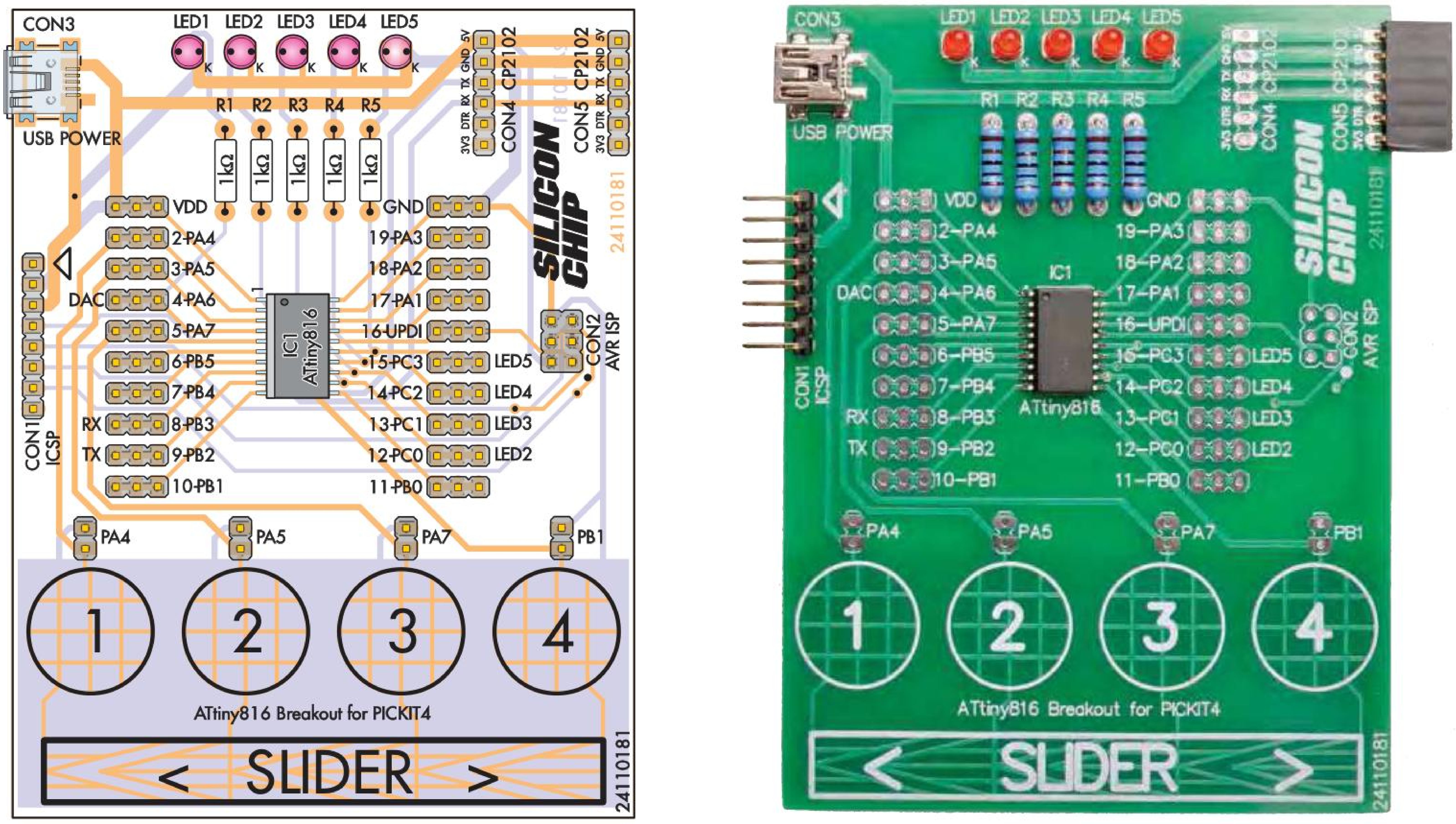


Fig.2: use this overlay diagram and photo as a guide during construction. You can choose to leave off parts that you don't need. The most interesting feature of this board is the network of tracks at the bottom which provide the same function as four pushbuttons and a slider but with no actual parts needing to be soldered to the board.

CON4 or a right-angle female header for CON5 if you want to be able to plug a CP2102 module into the board.

As noted above, you will probably not fit CON2 to the board. You would only do so if you are building it as a simple programming adaptor. In that case, CON1 and CON2 would normally be the only parts installed (possibly also CON3, if you want to be able to power the target from USB 5V). The 20 3-way male headers are the last essential components to fit. There is one for each pin on IC1.

We find it easiest to solder one pin of each group before the rest; this allows the header to be adjusted if it is not quite vertical, before soldering the remaining pins. You may also choose to leave the header pads vacant if you don't wish to do any prototyping, or you wish to solder components directly to the pads. The headers marked PA4, PA5, PA7 and PB1 allow you to connect to external touch-pads. These are not necessary if you will be using the onboard touchpads.

We recommend not fitting them until after you have experimented with the PCB touch pads – extra connections will affect the pads' capacitance and touch sensitivity.

Installing the software

You will need to install Microchip MPLAB X and the XC8 compiler on your system to compile the software and upload it to the chip. These are both free downloads from Microchip. But note that to get the full optimisations from XC8, you may need to pay for a license (*not* needed for this project.

The MPLAB X IDE (integrated development environment) is cross-platform software that is available for Windows, macOS and Linux, so download the version appropriate for your system from: **www.microchip.com/mplab/mplab-x-ide**

It allows you to edit and compile code, and upload the compiled code (HEX file) to the target chip – in this case, the ATtiny816.

The XC8 compiler converts the C code into a HEX file (and optionally also an assembly language file). This is integrated with MPLAB X, but you download and install it separately.

When you install the MPLAB X IDE, it will also install drivers for the PICkit 4, if you don't have them already. Ensure the PICkit 4 is plugged into your computer so that MPLAB X can identify it.

By the way, this software can also be used to program PICs and some other Atmel chips.

To use the AVR/PICkit 4 combination, you need to have MPLAB X version 5.05 or newer and XC8 version 2.00 or newer. Compilers, including XC8, can be downloaded from: **www.microchip.com/mplab/compilers**

You will also need to download the sample software for this project, available from the July 2021 page of the *PE* website. Extract the zip package to a convenient location.

Compiling the demo code

Once both packages are installed, launch the IDE, then use the File>Open Project menu option to locate and load the sample software that you extracted earlier. Next, right-click on the project name which appears in the left-hand pane, and select Properties.

Ensure Conf:[default] is selected, and check that your PICkit 4 is showing and selected under Hardware Tool, and that XC8 (v2.00) is selected under Compiler Toolchain.

If all this is correct, click OK, and connect the ATtiny816 PCB to the PICkit 4 via the 8-way header, ensuring the arrows marking pin 1 line up. You will also need to ensure that the PCB is powered, either from a CP2102 module or via the Mini-B USB socket.

Now click the button labelled 'Make and Program Device'. This looks like an IC with a green arrow pointing down. The software should compile and then upload the program to the board.

We have also provided a HEX file in the download package, which can be flashed directly to the ATtiny816 using the IPE (integrated programming environment) which is installed alongside the IDE, in case you are not interested in the code itself and don't want to compile it.

The demo code

The sample software we have written demonstrates some of the exciting capabilities of the ATtiny816 chip. It includes

Shared Capacitance Touch Sensing

Touch sensing technology allows simple and intuitive interfaces to be developed. While the touchscreens on our mobile phones are not quite the same thing as what we are demonstrating here, they use a similar phenomenon.

The human body has a measurable capacitance, and we can change the intrinsic capacitance of a circuit by coming in contact with it.

It may not even be a direct electrical contact; this effect works even when capacitively coupled across an insulating medium.

Hence the two advantages of the touch sensor: there does not need to be direct contact between the circuit and user; and the actual sensor is nothing more than a means of coupling to the user, in effect, an antenna.

In practice, the sensor is usually a PCB trace, perhaps matched by a second trace to shape and isolate the touch zone. This means the touch sensor has negligible extra manufacturing cost if the design already includes a PCB.

We implemented two different touch sensing algorithms in our demo code. The first was inspired by some Arduino code dating from over ten years ago, which will work with any digital I/O pin. It measures the time constant of an RC network consisting of a pin's internal pull-up resistance and the connected capacitance, including a finger if it is near the pad.

While simple to implement, it isn't very sensitive, with variations between the touch and no-touch state only differing by a count of one or two units. We haven't used the code at all in our demonstration, but have left it in the **touch.c** file supplied, for interest's sake.

The second method, which the QTouch Library firmware also uses, is called 'shared capacitance sensing'. It allows the value of an unknown capacitor to be determined using a known capacitance.

Imagine a capacitor C1, with a known capacitance. We fully discharge this capacitor by shorting both ends to ground. Next, we take an unknown capacitor Cx and charge it up to a known voltage VS by connecting one end to ground and the other to a supply of VS.

Now, we disconnect the capacitors from their respective supplies and connect them in parallel. This shares the charge between them, hence the name of the method.

Once the voltages have settled, we separate the capacitors and measure the voltage across either of them (which will be the same), and call this VF. Starting with the capacitor charge formula Q=CV, and knowing that:

$$Q_1 = 0 \text{ (because } V_1=0)$$

and

$$Q_x = C_x.V_s$$

thus:

$$Q_{total} = C_x.V_s$$

We can solve this to give:

$$C_x/C_1 = V_F/(V_S-V_F)$$

From this, we can see that the larger C_X is, the larger VF (our measured voltage) will be.

In practice, for touch sensing, the exact value of C_X does not need to be known. We just need to be able to detect a measurable change in its value.

In our ATtiny816, C1 is the ADC module sampling capacitor, which has a value of around 10pF. C_X is the capacitance of the item in contact with the sensor. Typical values for the human body are around 100pF, so we can see that this is at a reasonable level for detecting with our method, keeping in mind that the touch circuitry will add extra capacitance to this amount.

To discharge C1, we instruct the ADC to take a sample from its internal ground reference. To charge up C_X, we set the analogue input pin to have its internal pull-up current source switched on (this is actually left on in between samples, so that the circuit is always ready). This brings Cx up to Vs.

C1 will be disconnected from ground after its ADC sample is complete, and we disconnect C_X from its supply by disabling the internal pull-up current. The capacitors are automatically connected together by taking an ADC sample of the pin, and the ADC reading becomes the voltage reading (VF), which we could put into the above formula if we wanted to work out the value of the connected capacitance.

In practice, we take repeated ADC readings, and when we see a rise above a certain threshold, we report that a touch has occurred.

Our prototype circuit gives readings of around 680 ADC counts while idle, rising to 900 when a touch occurs. These are equivalent to capacitances of around 20pF rising to around 100pF during a touch event.

The slider uses a similar method, but combines the readings from several adjacent pins. In essence, the closer your finger is to one of the junctions in the slider, the more capacitance is detected at that point.

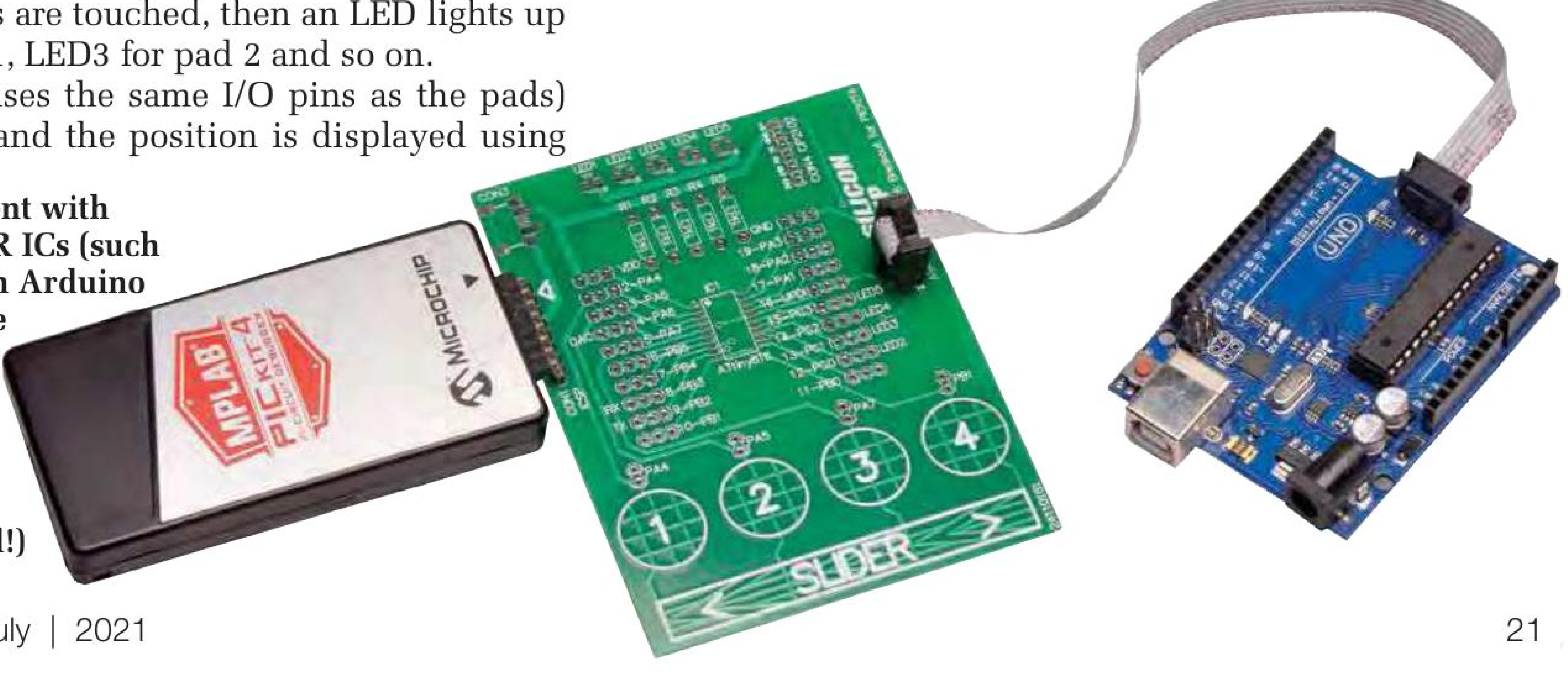
By performing a linear interpolation between the pin positions in proportion to their measured capacitance, we can calculate the approximate touch location.

functions to drive I/O pins, use the onboard DAC and ADC, the UART serial port, some basic real-time clock functions and capacitive touch sensing.

The code to do this is contained within the 'main' function of the **main.c** file, along with separate 'library' files which perform specific functions. We were inspired by the Arduino language to create some similar intuitively named functions for these purposes.

By default, the code continually monitors the touch pads on the PCB. If the pads are touched, then an LED lights up – LED2 lights for pad 1, LED3 for pad 2 and so on.

The slider (which uses the same I/O pins as the pads) position is also read, and the position is displayed using LED1. It lights at a low intensity with a finger touching the left-hand end and with high intensity at the right-hand end. The granularity that can be achieved can be demonstrated by gradually moving a finger along the slider. This code also demonstrates the use of IC1's internal DAC, which is used to fade LED1 in line with the touched position on the slider; it is not pulse-width modulated. Note that LEDs2-5 will also light up when the slider is used (and



If you want to experiment with programming other AVR ICs (such as the ATmega328 on an Arduino board), you can also use our PCB as an ICSP breakout for the PICkit 4. It appears configuration fuse programming is not supported yet. (We tried!)

The challenges of working with a new micro

With any new microcontroller, especially one that's using a new compiler and programmer combination, you're likely to run into a few minor roadblocks. Here's what we found when we first started programming the ATtiny816 using MPLAB X.

For a start, the XC8 compiler has traditionally been for PICs only, but they have now added AVR capability (both Microchip's XC8 and Atmel's avr-gcc are based on the GNU gcc compiler).

As a result of this history, the XC8 User Guide is PIC-oriented, and some of the documentation within does not apply to Atmel parts. For example, the syntax it gives for interrupt service routines (ISRs) is PIC-specific. The manual does not explain how to set up an ISR on an AVR part. Since we are using interrupts to handle the UART's serial receive event, we had to resolve this.

The code we were copying directly from the XC8 User Guide was being rejected by the compiler. Eventually, we found some code from an Atmel Studio project (the software which was used to program AVRs before Microchip's takeover). This compiled successfully. It has this format: `ISR(USART0_RXC_vect){}`

We ran into similar problems trying to program the AVR's configuration fuses (see the PIC vs AVR panel for an explanation of fuses). The tool for generating the micro's configuration bits creates code in the same style as for a PIC microcontroller, but again, it does not compile. Like with the ISR, we found some Atmel Studio code that worked instead. It looks like this:

```
FUSES = {
.APPEND = 0,
.BODCFG = ACTIVE_DIS_gc | LVL_BODLEVEL0_gc |
 SAMPFREQ_1KHz_gc | SLEEP_DIS_gc,.BOOTEND = 0,
   .OSCCFG = FREQSEL_20MHZ_gc,
.SYSCFG0 = CRCSRC_NOCRC_gc | RSTPINCFG_UPDI_gc,
.SYSCFG1 = SUT_64MS_gc,
   .WDTCFG = PERIOD_OFF_gc | WINDOW_OFF_gc};
```

In any case, we have commented out this section in our code, so that the programmer will not touch the fuse settings on the chip. The chip's default fuse values are suitable for our project, so leaving them as-is is a lower risk strategy.

We also struggled to find the device I/O header file, which tells the compiler where all the various special registers are located in RAM and provides various handy macros for controlling I/O pins and so on. Eventually, we found it on our system in this folder:

```
C:\ProgramFiles(x86)\Microchip\xc8\v2.00\dfp\include\avr\iotn816.h
```

We aren't sure what 'dfp' stands for. We also found, while experimenting with the compiler optimisation settings, that the code did not compile at all on optimisation level zero (no optimisation), but did so at level one.

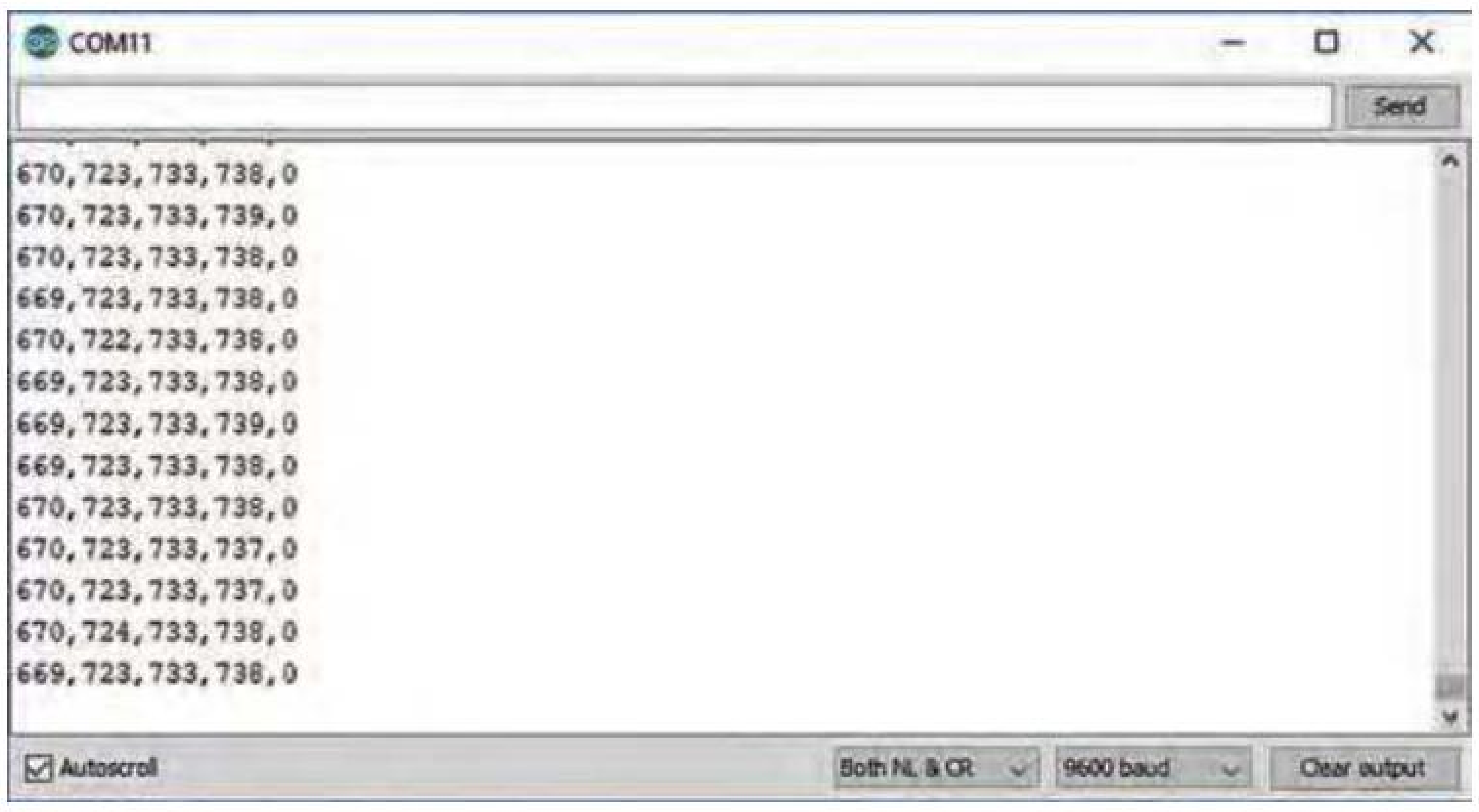
The error message said that the vector table had been truncated, which suggests that the compiled code may not fit in the available Flash space, but it only uses 29% of Flash space with optimisation enabled, so that seems like a huge difference.

With all the above in mind, we eventually got the code to compile and work. The MPLAB X support for AVRs is still at a beta stage, so we expect many of these problems will disappear over the next few months as support matures.

LED1 will change brightness when the pads are touched), since they are sharing the I/O pins on the microcontroller.

Serial debugging data

If you have a CP2102 USB-Serial module connected to CON4, you can also see the raw analogue touch values that are being sampled. Open a serial terminal program (eg, the Arduino Serial Monitor, PuTTY or TeraTerm) at 9600 baud, select the appropriate COM port and you will see the data being sent to the terminal.



```
670,723,733,738,0
670,723,733,739,0
670,723,733,738,0
669,723,733,738,0
670,722,733,738,0
669,723,733,738,0
669,723,733,739,0
669,723,733,738,0
670,723,733,738,0
670,723,733,737,0
670,723,733,737,0
670,724,733,738,0
669,723,733,738,0
```

Fig.3: example output of the ADC sample values corresponding to the sensed relative capacitance for each of the four pushbuttons and the slider. You can see that the four first values are fairly steady over time, while the last value is zero. If you bring your finger near or touch a button, one of the values will increase, indicating the added capacitance from your finger.

If you have one of the more recent versions of the Arduino IDE (we are using version 1.8.5), you can also use its Serial Plotter function to show the values as a graph. This can be found under the Tools menu.

The first four numbers printed on each line are the raw ADC readings from each touchpad on a scale from 0 to 1023 (see Fig.3).

You can use this information, along with the formulas from the sidebar about *Shared Capacitance Touch Sensing*, to estimate the actual capacitance connected to the pin before, during and after a touch has occurred.

The final number is the calculated slider value, which is zero if no touch has occurred and in the range 20 to 80 if a touch is occurring. The values are arbitrary but demonstrate the resolution of the slider pad.

If you find that touches are not being consistently and accurately detected, then the threshold and baseline levels in the program may need to be adjusted. A touch is detected when the raw ADC value rises above the baseline plus threshold value, so this should be set about halfway between the touched and untouched ADC values.

Conclusion

We found the ATtiny816 to be a capable device, and it was easy to work with once we had figured out the quirks of the compiler. But we were a bit disappointed that we could not think of good ways to demonstrate the other features of the microcontroller, such as the CCL or Event System. The 20MHz internal oscillator mode is rated to work down to around 4.5V supply voltage, but we did some tests with a 3.3V supply and found most things seemed to work adequately.

But the performance does degrade slightly. For example, the ADC results appeared to drift more than with a 5V supply. Another ATtiny series chip (ATtiny85), has even had a USB stack ported to it, so if the same can be done for the ATtiny816, then we can expect some interesting projects to appear.

The small amount of RAM and Flash memory appears to be limiting, but we expect this microcontroller will make a great peripheral IC to another micro, and we look forward to using it for other projects.

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Infrared Remote Control Assistant

Remote controls are handy, but sometimes equipment makes their use quite clunky. Selecting between live TV, DVD/Blu-ray, pay-TV and Internet streaming on a television often requires you to press several different buttons in sequence. Now, these sequences can be performed at the press of a single button using the *Infrared Remote Control Assistant*.

By John Clarke

It's even more annoying when the multiple steps require the use of more than one remote control! If you have several sources connected to your TV, you may need to open the 'source' menu and use the up/down or left/right buttons on its remote control to select the source and then press 'Enter' to select that input.

There can be even more presses involved to access Internet streaming services. This *may* be OK for you (you probably set the TV up), but your spouse, parents and friends probably don't appreciate the complexity, and may well not be able to figure out how to do this.

The *IR Remote Control Assistant* helps solve this. It vastly simplifies the procedures by recording the sequence and then replaying it whenever a button is pressed.

It isn't just useful for these complex remote control sequences. It can also perform the same task as a single button press on multiple remotes, so you can perform common tasks without having to go to the device's specific remote control.

For example, you might want to set up the *IR Remote Control Assistant* to provide volume control as well as handling complex sequences.

What about learning remotes?

Many universal remote controls have a learning function, but they are designed to provide a single function for each button switch. They can't store a long sequence of infrared codes.

With the *IR Remote Control Assistant*, there are eight push button switches and each can be used to store separate infrared remote control sequence procedures in memory. It not only stores the codes required in the right sequence, but also the delay between each button press. This may be important, as some sequences require you to wait until the device is ready to proceed with more button presses.

It can typically store up to 100 separate remote control codes in each sequence (ie, up to 800 codes total). Sequences can run for up to about two and a half minutes, although the total time may be reduced if there are many complex codes involved.

For example, for ten typical button presses, the maximum sequence time is two minutes and 36 seconds but for 50, it drops to about one minute and 20 seconds.

In practice, you're unlikely to require a code sequence so long in either number of codes or time duration that you run out of memory. And the unit can record eight separate sequences; each is allocated its own memory space.

Presentation

The *IR Remote Control Assistant* is housed in a remote control case that has a separate battery compartment. The eight sequence pushbuttons are on top, while at the front is the infrared (IR) LED that sends the codes to the TV or other device.

There is also an IR receiver used to receive the infrared codes for recording sequences. A small switch is included to select between the record or play mode, while a visible-light LED indicates operation.

The *IR Remote Control Assistant* is easy to use. Once it has been programmed, just press one of the eight pushbuttons to replay a stored IR sequence. The LED indicator flashes in response to the code being sent. While the *IR Remote Control Assistant* is playing back an infrared sequence, it can be stopped by pressing any button.

Programming sequences is also quite easy; this is described below, after the construction section.

Circuit description

The full circuit is shown in Fig.1. It's based around 8-bit microcontroller IC1, which is the electronic 'brains' behind the *IR Remote Control Assistant*. While we've often used the PIC16F88 in the past, that part is now no longer recommended for new designs and is becoming more expensive. The PIC16F1459 has a lot more features, but despite that, it is cheaper.

IC1 stores the programmed code sequences in 1Mbit serial RAM chip IC2. Remote control codes from other devices are picked up by infrared receiver IRR1 and fed straight to the RA5 digital input of IC1 (pin 2). IRR1's 5V power supply is switched by MOSFET Q1 and filtered using a 47Ω series resistor and 10µF bypass capacitor, to provide clean power to IRR1; it is sensitive to supply noise.

MOSFET Q1's gate is driven directly from the RC4 digital output of IC1 (pin 6). Since Q1 is a P-channel MOSFET, IRR1 is powered when pin 6 is low, and switched off to save power when pin 6 is high.

When transmitting infrared remote control code sequences, IC1 drives its RC5 digital output (pin 5) high. This forward-biases NPN transistor Q3's base-emitter junction, with the current limited to a few milliamps by its 1kΩ base resistor.

While switched on, Q3 sinks about 25mA from the cathode of infrared LED1. It does this in pulses, so the average LED current is less than 10mA during pulses, and less if

Features and specifications

- Deep memory storage
- 666.66ns sampling resolution
- Eight separate independent selections available
- Up to 100 separate IR code storage possible per procedure
- 174s (2m 54s) maximum record time per procedure
- 34.4kHz to 41.66kHz modulation adjustment range, in 15 steps
- Easy learning or record function
- Automatic memory erase before recording on each selection
- Bulk erase of all eight selections available
- Indicator LED
- Adjustable infrared modulation frequency
- Battery powered, with low standby current (3.3µA typical)

averaged over the whole transmission. The RC5 output is pulse-width modulated (PWM) running at close to a 32% duty cycle.

Trimpot VR1 adjusts the modulation frequency for infrared LED1. The voltage at its wiper is converted to a digital value at the AN8 analogue input of IC1 (pin 8). After processing, this value provides a modulation frequency for RC5 between 34.4kHz when fully anticlockwise and 41.66kHz when fully clockwise.

Infrared remote controls tend to use a frequency of either 36kHz, 38kHz or 40kHz. The adjustment is provided to obtain the best results during use. Typically, setting the frequency to 38kHz (mid-position of VR1) will suit all IR receivers, provided the *Assistant* is reasonably close to the receiver. More range might be available at a different frequency setting selected with VR1.

The LED indicator (LED2) lights up in response to the IR code during the recording of infrared signals and as a sending data indicator when replaying infrared signals. It is driven via the RC3 output (pin 7) via a 1kΩ resistor. The RC3 output also powers up one side of VR1 when set high, saving 0.5mA the rest of the time.

Button sensing

Pushbutton switches S1-S9 are connected in a 3 × 3 matrix with the RC0, RC1 and RC2 outputs (pins 16, 15 and 14) connecting to one side of the switches and the RA1, RA4 and RA0 inputs (pins 18, 3 and 19) connecting to the other side.

Note that RA1 and RA0 have 100kΩ pull-up resistors to the 3.3V supply, but RA4 does not. That's because the RA4 input of IC1 can be configured with an internal pull-up to 5V, via the software.

The reason that RA1 and RA0 do not have this feature is that on this chip, they can also be used as the USB D+ and D– signal lines. These pins thus operate somewhat differently from other I/O pins when USB mode is disabled. Their pull-ups are designed to suit the USB specifications rather than be used as general-purpose pull-ups.

The reason that the 100kΩ resistors go to the 3.3V rail rather than the 5V rail is that these USB-specific pull-ups are implemented via internal P-channel MOSFETs within IC1, and their sources connect to the +3.3V rail. So, if we pulled these pins up to +5V then the 3.3V supply voltage would rise, as the intrinsic reverse diodes in these P-channel MOSFETs would conduct.

That would cause the 3.3V supply to rise to around 4.7V. That usually would not be a problem, but we use the 3.3V supply to provide memory backup for IC2. And as we shall see later, this voltage is already near the maximum allowed for that purpose.

That leaves us with the question of whether 3.3V is sufficient for the RA0 and RA1 inputs to differentiate between high and low levels. It turns out that the minimum voltage that is guaranteed to be detected as a high level for these pins is $V_{dd} \div 4 + 0.8V$, which for the highest possible V_{dd} of 5.15V, is still less than 2.1V. So the pull-ups to the 3.3V rail work fine.

To detect if any switch is closed, all RC0, RC1 and RC2 outputs are taken low in sequence. The RA1, RA4 and RA0 inputs will typically be high due to the pull-ups. However, one input will be held low if a switch is pressed. The combination of which of the three sets of pins are low tells us which button was pressed.

Note that if more than one switch is pressed at a time, then the first detected closed switch will be the one that's deemed to be closed. When we require two switches to be closed, such as when clearing memory for an individual switch, switch S9 (the Mode switch) is checked for closure independently from the other switches.

Recording

As described earlier, infrared receiver IRR1 is used for recording the infrared code and its power is controlled by MOSFET Q1. Before recording, the supply voltage for IRR1 is increased slowly to 5V over 13ms.

This is done by applying brief low pulses (2/3ns long) to its gate, with a repetition rate starting at 66µs and reducing until the gate is held fully low. The reason we do this is so that IC1 does not reset due to a momentary drop in its supply voltage, which can happen if IRR1 is instantly switched on, due to its 10µF bypass capacitor and the limited current that can be supplied by the 9V battery.

SILICON CHIP Remote Control Assistant
TV - Foxtel
TV -FTA
DVD
X-BOX
1 2
3 4
5 6
7 8
2 Mute
4 Change input
6 Pause
8 Switch DAB+ and FM

Once powered, IRR1 is ready to receive IR codes. Most infrared controllers use a modulation frequency of 36-40kHz. This is done in bursts (pulses), with the length of and space between the bursts (pauses) indicating a code.

The series of bursts and pauses are usually in a particular format (or protocol), and there are several different protocols commonly used.

This includes the Manchester-encoded RC5 protocol originated by Philips. There is also the Pulse Width Protocol used by Sony and Pulse Distance Protocol, originating from NEC.

If you are interested in details on all these protocols and others, see the *Infrared coding* box from August 2020 in the *Steering Wheel Audio Button to Infrared Adaptor* project.

The output from IRR1 is a demodulated version of the infrared signal, which is high (5V) when there is no signal and low (near 0V) when a 36-40kHz modulated burst is detected. We record the level and duration of each pulse to memory when recording. The recorded sequence is reproduced during playback by modulating LED1 in bursts. It is driven as described above.

Memory

The memory chip is a 1024kbit (1Mbit) memory organised as 128kbytes. The memory is accessed over a simple

Serial Peripheral Interface (SPI) bus. When writing, data is sent to the SI input of IC2 (pin 5) from the SDO (pin 9) output of IC1. When reading, data is received from the SO output of IC2 (pin 2) to the SDI input (pin 13) of IC1.

In both cases, the data is clocked using the signal from the SCK (pin 11) of IC1 to the SCK input of IC2, at pin 6. Communication with IC2 is enabled by a low level at the chip select (CS), driven from pin 10 of IC1 (RB7) and sensed at pin 1 of IC2.

When writing to memory (after power is applied via Q2), the memory is selected by bringing the chip select input low. Then a write instruction is sent, followed by the desired memory address from which to start. This is a 24-bit address sent as three 8-bit bytes. The seven most significant address bits are always zero, since only 17 bits are required to address the 128k bytes.

Following this, data can be written. The memory powers up in sequential mode where the address automatically increments after each byte is written.

The signal from IRR1 consists of a series of high and low levels. These levels are monitored at a fast rate, but we don't store each sampled level directly into memory. That would chew up the memory too quickly. For example, sampling at a rate of 1.5MHz (ie, each 2/3μs) and storing that level in successive bits, the entire 1Mbit of memory would be full after 2/3 of a second!

So instead, we sample the level each 666.66ns, but we don't store this directly in memory. Instead, we continue to monitor the level and record how long it remains at the same level before changing. The level and duration of each pulse are stored every time the level changes.

To store this, we use two consecutive 8-bit address locations (16 bits total). The most significant bit (bit 15) stores the level while the remaining 15 bits are used to store the length of the pulse, in 666.66ns intervals.

The maximum value we can store in 15 bits is 32,768, so the maximum period stored in each 16-bit memory location is 32,768 × 666.66ns, or 21.845ms. If the data level does not change within the maximum period, we continue storing the duration of that same level into the next 16-bit-wide memory slot. This is a form of 'run-length encoding' data compression.

For our project, we further divide up the memory into eight separate 16kbyte blocks. So the first 16kbyte block is reserved for the sequence stored using switch 1, the second 16kbyte block is for switch 2 and so on, up to switch 8 for the last 16kbyte block.

To read the stored data, the CS input of the memory is taken high and then low again to select the memory, and the read instruction is sent along with the 24-bit address location. Then the data is read out in sequence.

Power for IC2 is switched on or off via another P-channel MOSFET, Q2. This conserves power as the IR Remote Sequencer will be sitting dormant most of the time, so it makes sense to power off the memory. It draws around 3mA when active, but only 4μA in standby.

Data stored in the memory is maintained when power is removed from IC2 by supplying a voltage to the battery backup (V_{BAT}) at pin 7. This derives power from the 3.3V supply from the internal 3.3V regulator in IC1 that's intended to power its USB peripheral. This is available at the V_{USB3V3} pin, pin 17. The voltage range for V_{BAT} is 1.4-3.6V, so this 3.3V supply (3.0-3.6V tolerance range) is ideal.

Power for V_{BAT} is applied via D2 and a series 47kΩ resistor. A 100μF low-leakage capacitor holds power to V_{BAT} for a substantial period (more than 100s) during the period while the battery is changed. D2 diode isolates V_{BAT} from the 3.3V supply that will drop to zero when the battery is disconnected.

The 100μF capacitor is only discharged through leakage in the capacitor itself and via discharge at V_{BAT}, at around 1μA.

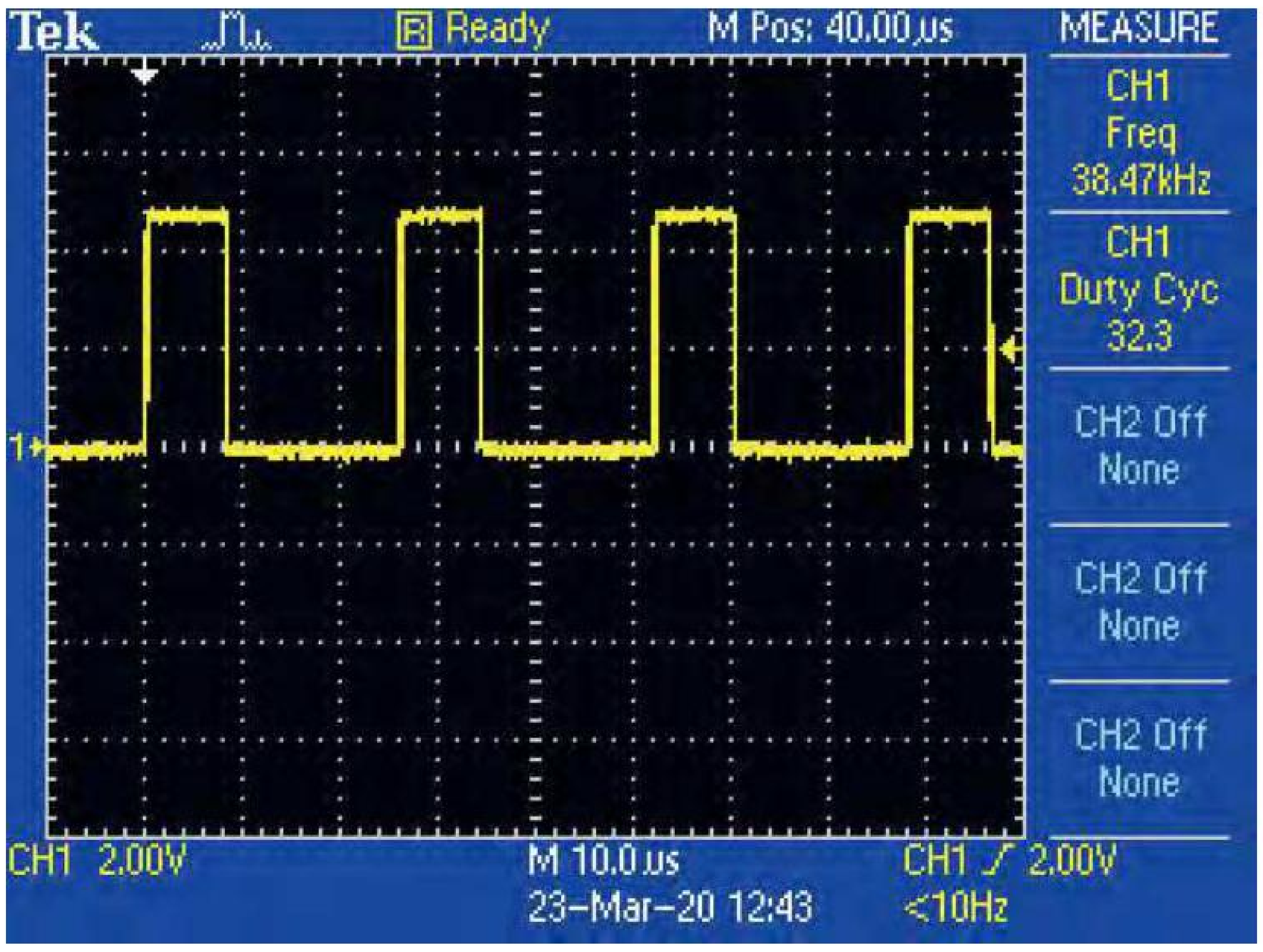
Power

The circuit is powered from a 9V battery that is regulated down to 5V using an ultra-low quiescent current regulator that typically only draws 2μA at low output currents. Reverse polarity protection is via schottky diode D1. There are two 1μF ceramic bypass capacitors, one at the input and one at the output of the regulator for supply decoupling and to ensuring regulator stability.

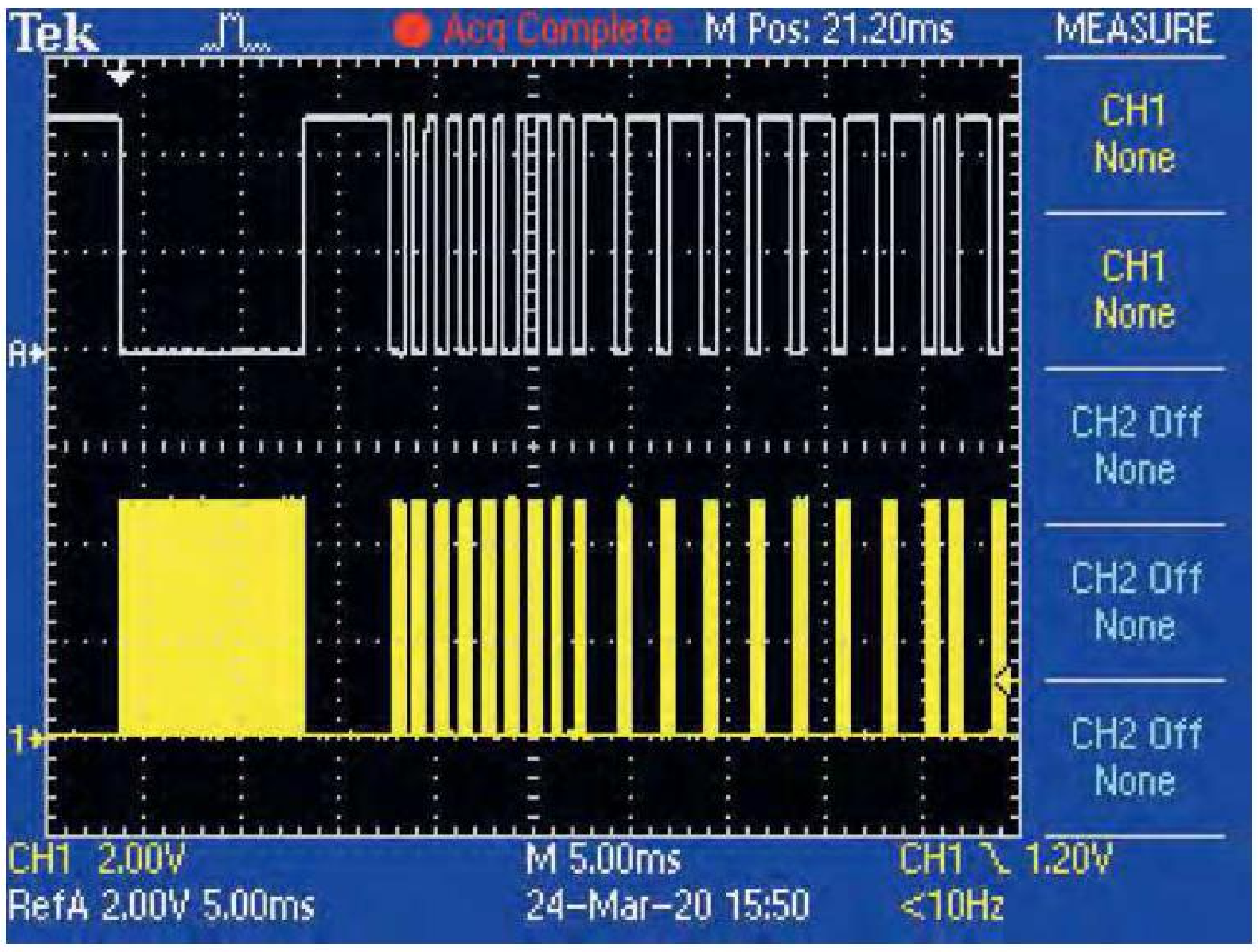
The 5V supply is also bypassed with a 10μF electrolytic capacitor and a 100nF capacitor near IC1.

Saving power

Since we are powering the *IR Assistant* from a battery, power draw needs to be minimised. This is done by only powering parts when they are needed and placing IC1 in a sleep state unless it is required to record or play infrared code. In sleep mode, IC1 typically draws just 0.3μA. IC1 is woken from sleep when a switch is pressed.



Scope1: this shows the modulation of the infrared signal from pin 5 of IC1. This drives transistor Q3 which controls infrared LED1. The modulation frequency is around 38.5kHz, as VR1 is set mid-way. VR1 can be used to set the frequency from 34.4kHz to 41.66kHz. The duty cycle is fixed at about 32%.



Scope2: the top trace is a capture of an infrared signal, measured at the pin 1 output of IRR1. The lower trace shows the output at pin 5 of IC1 after that infrared coded signal shown in the top trace was stored in memory and replayed, which is shown inverted and also modulated at 34.4kHz.

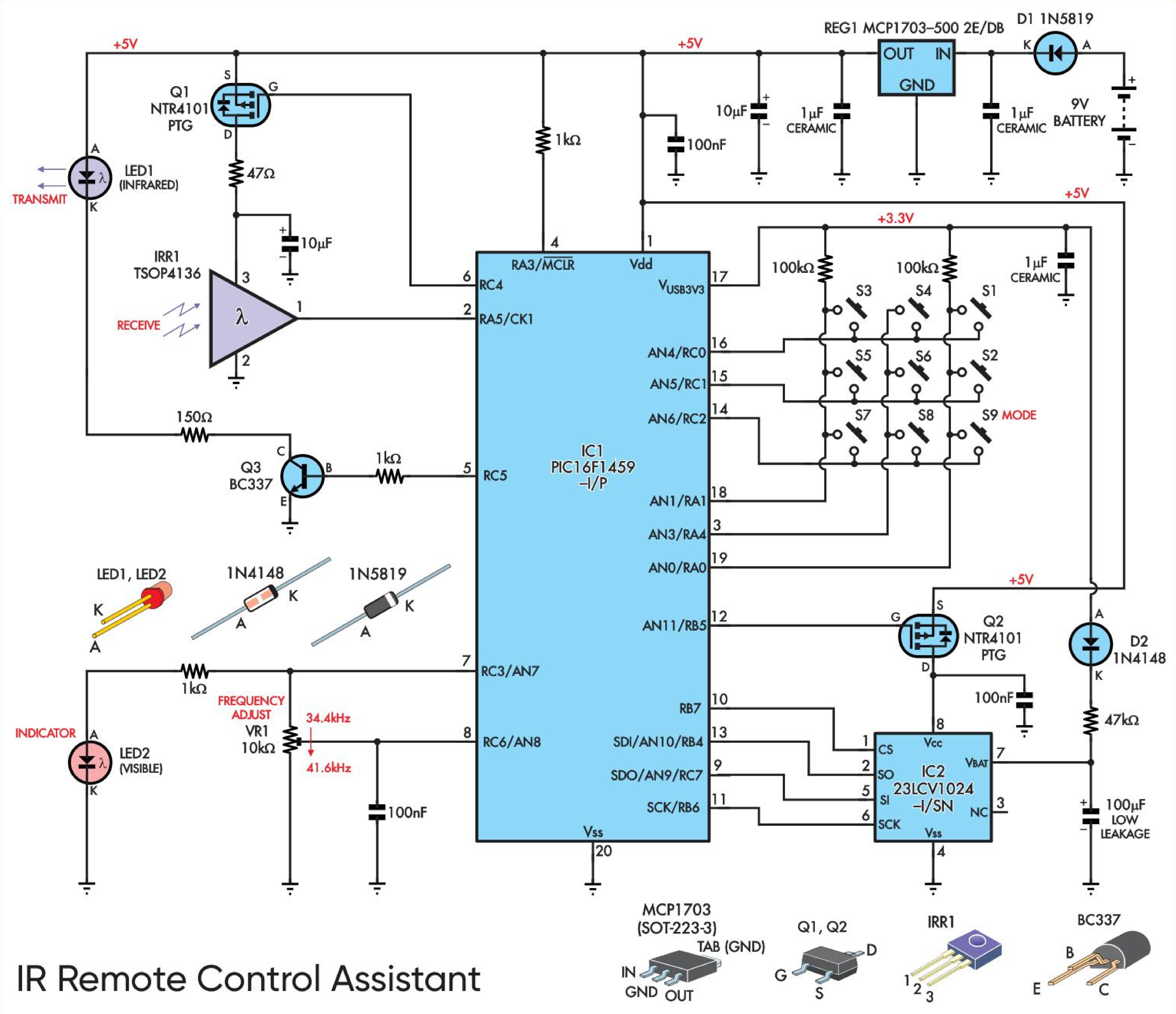

IR Remote Control Assistant
+5V
Q1 NTR4101 PTG
S
G
D
47Ω
LED1 (INFRARED)
TRANSMIT
A
K
10µF
IRR1 TSOP4136
RECEIVE
λ
1
2
3
150Ω
Q3 BC337
C
B
E
1kΩ
REG1 MCP1703–500 2E/DB
OUT
IN
GND
D1 1N5819
10µF
1µF CERAMIC
100nF
1µF CERAMIC
9V BATTERY
+3.3V
100kΩ
100kΩ
1µF CERAMIC
S1
S2
S3
S4
S5
S6
S7
S8
S9 MODE
IC1 PIC16F1459 –I/P
RA3/MCLR
Vdd
RC4
RA5/CK1
VUSB3V3
AN4/RC0
AN5/RC1
AN6/RC2
AN1/RA1
AN3/RA4
AN0/RA0
AN11/RB5
RC5
RC3/AN7
RC6/AN8
RB7
SDI/AN10/RB4
SDO/AN9/RC7
SCK/RB6
Vss
Q2 NTR4101 PTG
100nF
D2 1N4148
47kΩ
IC2 23LCV1024 –I/SN
CS
SO
SI
SCK
Vcc
VBAT
NC
Vss
100µF LOW LEAKAGE
INDICATOR
LED2 (VISIBLE)
FREQUENCY ADJUST
VR1 10kΩ
34.4kHz
41.6kHz
100nF
LED1, LED2
1N4148
1N5819
MCP1703 (SOT-223-3)
TAB (GND)
IN
GND
OUT
Q1, Q2
IRR1
BC337

Fig.1: the circuit of the *Assistant* is not too complicated. It's based around microcontroller IC1 which records infrared pulses sensed by receiver IRR1 into RAM chip IC2. It can later read these back and reproduce them by flashing infrared LED1 via transistor Q3, when triggered by a press of button S1-S8.

Other parts powered off include the infrared receiver (IRR1), memory chip IC2, indicator LED2 and trimpot VR1.

Overall current drain in standby is thus 0.3µA for IC1 plus 1µA for IC2's V_{BAT} input and 2µA for regulator REG1. This is about 3.3µA total, although we measured 2.7µA on our prototype. If the *IR Remote Control Assistant* is used for one minute per day, that adds about an average of 7µA current draw over the day.

Assuming a conservative 400mAh capacity for a 9V alkaline battery, we can expect the battery to last four years. That's almost the shelf life of the battery itself, which would typically be five years. More frequent usage of the *IR Remote Control Assistant* will reduce the battery life a little.

Construction

The *IR Remote Control Assistant* is housed in a remote control case and built on a double-sided PCB. We've designed two different PCBs – both available form the *PE PCB Service* – to suit different remote control cases. For the Jaycar HB-5610 remote control case, the PCB is coded 15005201 and measures 63.5mm × 86mm. The PCB coded 15005202 and measuring 58.5 × 86mm suits two Altronics cases, either H0342 (Grey) or H0343 (Black). A panel label attaches to the front face of the box in each case, so you know what the unit and its controls do.

Select the correct PCB to suit your case and refer to the relevant PCB overlay diagram: Fig.2 for the Jaycar case or Fig.3 for the Altronics case.

Start assembly by soldering IC2 in place. This is a surface-mounting device, best fitted by placing it in the correct position and soldering one of the corner pins to the PCB pad. Check that the IC is aligned and oriented correctly before soldering the remaining pins. If it is not aligned, remelt the solder on the pin and align the IC again.

Any solder bridges between the leads can be cleared using solder wick to draw up excess solder. Solder wick works best when a little flux paste is applied to the bridge first.

Fit Q1, Q2, REG1 and the three 1µF ceramic capacitors next, using a similar technique. Two of the capacitors are near REG1, while the other is on the opposite side of the PCB, underneath IC1.

Install the resistors next. You can read the resistor colour code to figure out the resistor values, but it's best to use a digital multimeter to measure each value. The diodes can then be installed, and these must be mounted with the orientations as shown. Note that D1 is a 1N5819 type while D2 is a smaller 1N4148.

It's a good idea to mount IC1 using an IC socket. When installing the socket, take care to orient it correctly. Its notch

Fig.2 (left): use this PCB overlay diagram as a guide when building the version of the *Assistant* that fits into a Jaycar remote control case. Start assembly with the SMDs: IC2, Q1-Q2, REG1 and the three 1µF ceramic capacitors. Watch the orientations of IC1, IC2, D1, D2, LED1, LED2, Q3 and the electrolytic capacitors.

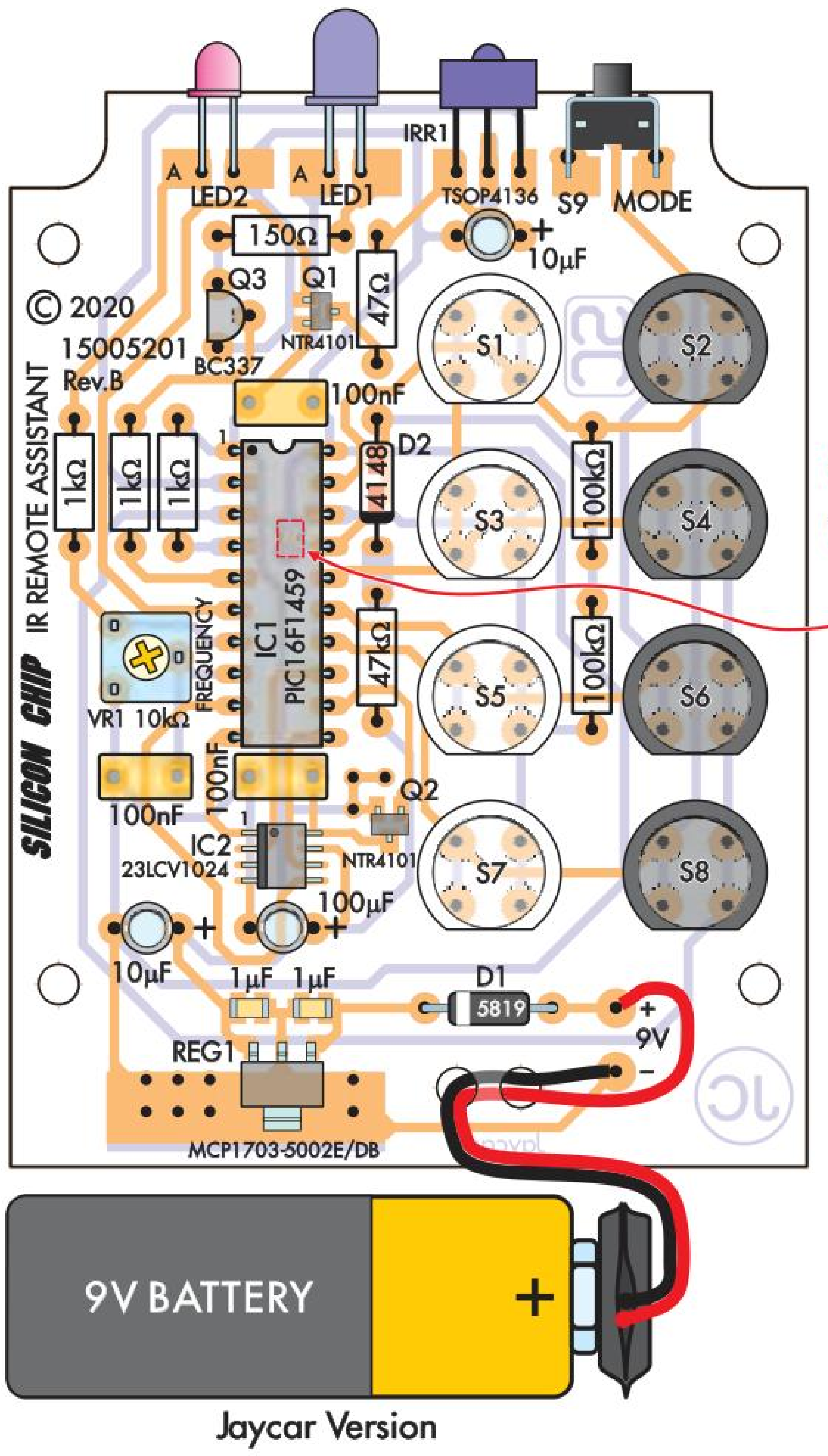
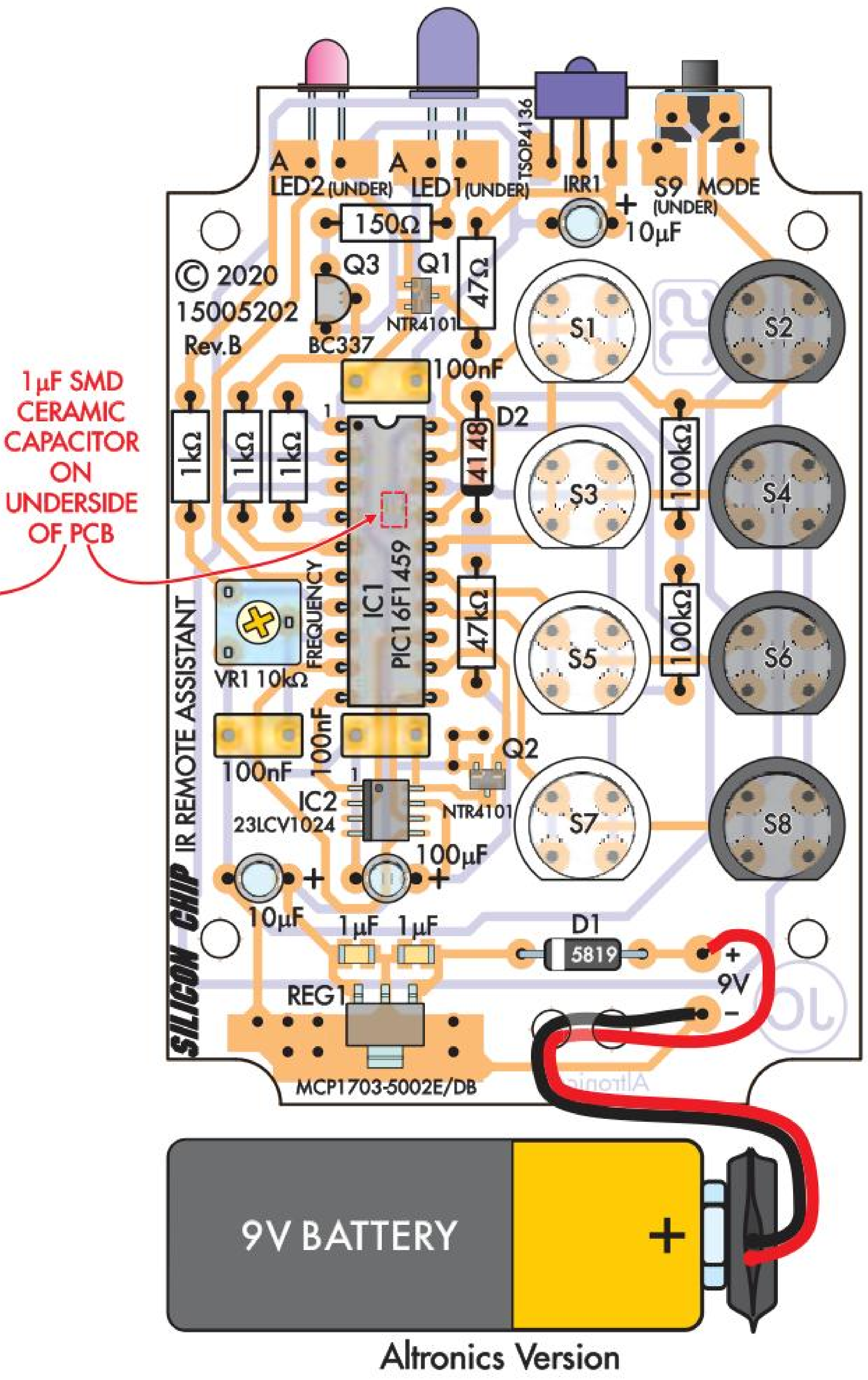

LED2
LED1
IRR1
TSOP4136
S9
MODE
A
150Ω
10µF
© 2020
15005201
Rev.B
Q3
Q1
47Ω
BC337
NTR4101
S1
S2
100nF
D2
IR REMOTE ASSISTANT
1kΩ
1kΩ
1kΩ
4148
100kΩ
S3
S4
IC1
PIC16F1459
FREQUENCY
VR1 10kΩ
47kΩ
100kΩ
S5
S6
SILICON CHIP
100nF
100nF
Q2
IC2
23LCV1024
NTR4101
S7
S8
100µF
10µF
1µF
1µF
D1
5819
REG1
MCP1703-5002E/DB
+
9V
–
9V BATTERY
+
Jaycar Version

Fig.3 (right): this is the PCB overlay diagram for the version which fits into an Altronics remote control case. Construction is similar to the PCB shown in Fig.2, except that LED1, LED2, S9 and IRR1 are mounted on the other side of the board, and IRR1's leads are cranked differently.


1µF SMD CERAMIC CAPACITOR ON UNDERSIDE OF PCB
LED2 (UNDER)
LED1 (UNDER)
IRR1
TSOP4136
S9 MODE (UNDER)
A
150Ω
10µF
© 2020
15005202
Rev.B
Q3
Q1
47Ω
BC337
NTR4101
S1
S2
100nF
D2
1kΩ
1kΩ
1kΩ
4148
100kΩ
S3
S4
IC1
PIC16F1459
FREQUENCY
VR1 10kΩ
47kΩ
100kΩ
S5
S6
IR REMOTE ASSISTANT
SILICON CHIP
100nF
100nF
Q2
IC2
23LCV1024
NTR4101
S7
S8
100µF
10µF
1µF
1µF
D1
5819
REG1
MCP1703-5002E/DB
+
9V
–
9V BATTERY
+
Altronics Version

should be positioned as shown. Then fit trimpot VR1 and transistor Q3.

The capacitors can go in next, with the electrolytic types oriented with the polarities shown (the longer lead is positive). Make sure these capacitors are fitted so that their height above the PCB is no more than 12.5mm; otherwise, the case lid may not fit.

Parts varied by version

LED1, LED2, IRR1 and pushbutton S9 are mounted differently depending on the version you are building. For the version that fits into the Jaycar case, these parts mount on the top side of the PCB.

Bend LED2's leads down by 90°, 6mm back from the base of its lens, making sure the anode lead is to the left. The LED then sits horizontally with the centre of the lens 6mm above the top of the PCB.

Similarly, LED1 mounts horizontally 6mm above the PCB, except its leads should be bent some 4mm back from the lens base, again ensure that the anode is to the left. IRR1 is also mounted with the centre of its lens 6mm above the PCB. Bend its leads in a dog-leg shape, so the front of its lens lines up with the LED lenses.

For the Altronics version, LED1, LED2, IRR1 and pushbutton switch S9 mount on the underside of the PCB.

For LED2, bend the leads up by 90°, 6mm from the lens base, making sure that the anode lead is to the left. The LED then mounts horizontally with the centre of the lens 4mm below the bottom of the PCB board. LED1 is also mounted horizontally but 3.5mm below the PCB, with its leads bent some 4mm back from the LED base, again ensuring that the anode is to the left.

IRR1 should also be mounted with the centre of its lens 4mm below the bottom of PCB. Insert its leads from the top and then bend them down by 90° so that the body swings beneath the PCB. A cutout is provided for its leads to pass to the other side of the PCB without sticking out. The back of the lens should be in line with the front edge of the PCB.

More common parts

Switches S1-S8 are mounted with the orientation shown, with the flat side to the bottom edge of the PCB. We used four white-topped and four black-topped switches, although any colour or colour combination can be used.

For the Jaycar case, the battery snap is inserted from the battery compartment side first, with the leads passed through to the PCB. For both versions, the leads from the battery snap pass through wire stress relief holes that are on the PCB.

First feed the wires through the outside 3mm hole, then under the PCB and up through the next 3mm hole. Then solder the ends directly to the plus (red wire) and minus (black wire) pads.

Testing

Apply power and check that there is 4.75-5.25V between pins 20 and 1 of IC1's socket. If that is correct, disconnect power and insert IC1. Check that LED2 lights when the Mode switch (S9) is pressed.

Press the Mode switch again so that LED2 goes off. Then press one of S1-S8. The LED should light up. Stop the playback of whatever random data was in the memory chip by pressing any of S1-S8.

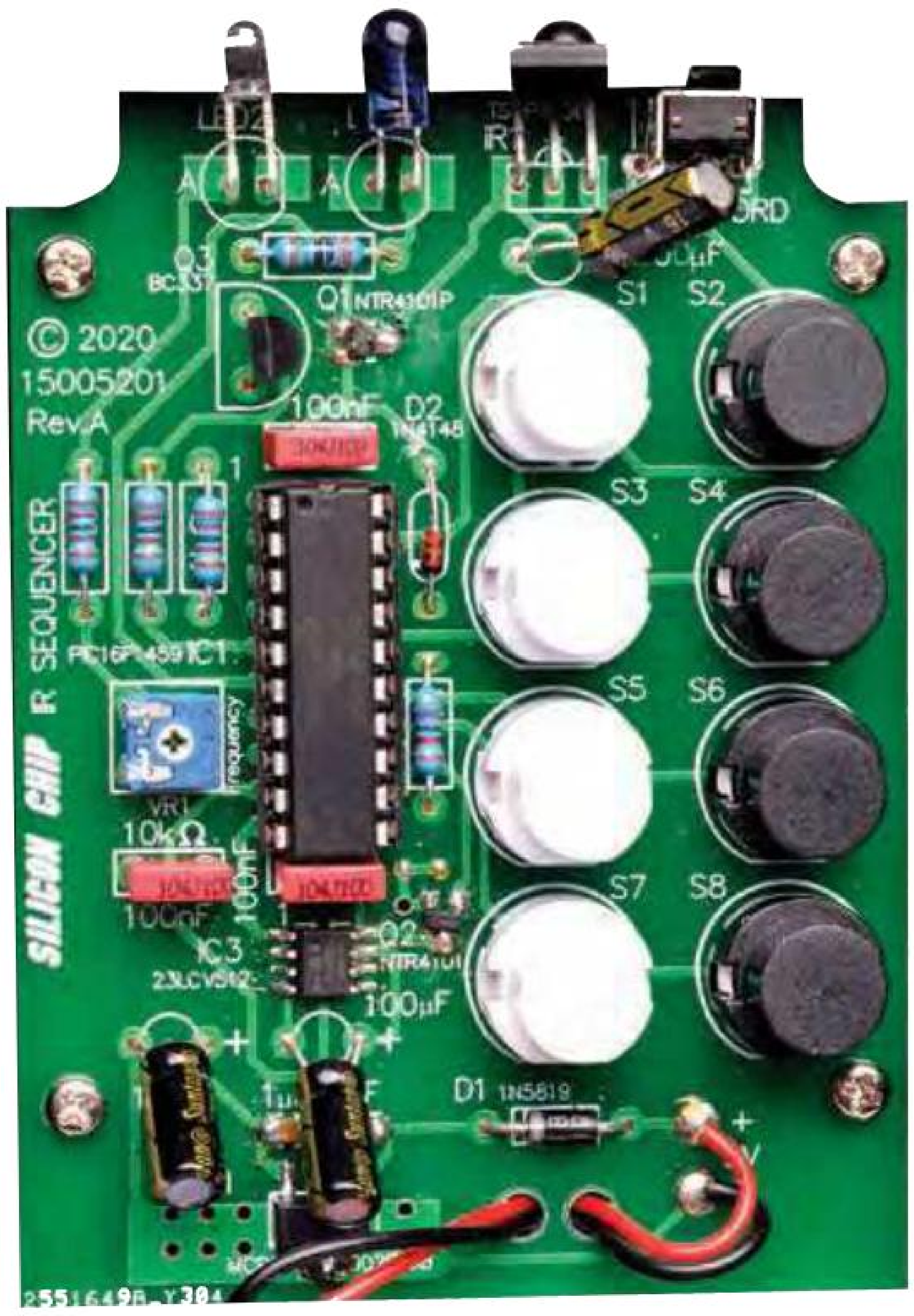
Next, clear the memory by pressing the Mode switch (LED2 will light) and holding this switch closed for 10 seconds until the LED flashes to indicate that all memory has been cleared. You can test if the memory has been cleared by pressing any of the S1-S8 switches. If cleared, LED2 will just flash momentarily.

Finishing the case

Drill out the end panel for the LEDs, IR receiver and switch. A drill guide is available and is provided with the front panel label that's included with the front panel artwork. This can be downloaded from the July 2021 page of the *PE* website.

For the Altronics case, it is essential to place the drilling template onto the end panel with the correct orientation before drilling.

The top panel of each case can then be drilled out for the eight switches using the drilling template that's a part



This same-size photo matches the Jaycar PCB layout opposite (Fig.2) but the Altronics version (Fig.3) is virtually identical, albeit on a slightly narrower PCB. Make sure the battery wiring is threaded through the strain relief holes, as shown here and on the diagrams.

of the front panel label artwork. Again, make sure the top panel is oriented correctly before drilling.

Drill a small hole first and gradually enlarge the holes with a reamer. As you enlarge the holes, regularly check that each hole is located correctly and is not too large by placing the panel over the assembled PCB and switches. Countersinking the inside of the holes can help locate the switches better as the panel is brought up to meet the switches.

The front panel artwork includes rectangular blank labelling borders for each switch. This can be written onto using the 'fill and sign' option on a PDF reader before printing. Alternatively, use a fine-point permanent marker on the label itself to indicate what each switch is programmed for. More space is provided for switches S2, S4, S6 and S8 than for S1, S3, S5 and S7.

A front panel label can be made using overhead projector film, with the label printed as a mirror image so the ink will be between the enclosure and film when affixed. Use projector film that is suitable for your printer (either inkjet or laser) and affix using neutral-cure silicone sealant.

For black cases, use a light-coloured silicone. Light-coloured cases can use clear silicone, such as the roof and gutter type. Squeegee out the lumps and air bubbles before the silicone cures. Once cured, cut holes in the film for the switches with a hobby or craft knife.

INDICATOR
I-R TRANSMIT
I-R RECEIVER
MODE

Looking at the top of the Jaycar case version – it's simply a matter of 'point-n-shoot' – press the button for the previously programmed action required.

Mounting the PCB

The PCB attaches to the base of the Jaycar case using four self-tapping screws into the integral mounting bushes.

The PCB for the Altronics case is mounted on the lid section using 5mm spacers and 9mm self-tapping screws. If the spacers are M3 tapped, they will need to be drilled out with a 3mm drill to allow the self-tapping screws to enter freely. Finally, attach the lid to the case using the four screws supplied with the case.

Programming it

Orient the *IR Remote Control Assistant* with the front end of the case with the LEDs and IR1 facing you and placed near the audiovisual items you are using.

To record the IR sequences required, place the *Assistant* in record mode by pressing the 'Mode' switch using a

Parts list – IR Remote Control Assistant

1 panel label (see text)
1 20-pin DIL IC socket
8 click action pushbutton switches, any colours (S1-S8)
  [eg, Jaycar SP0720-4, Altronics S1094-1099]
1 right-angle (RA) tactile pushbutton switch (S9) [Jaycar SP0604]
1 9V battery
1 9V battery clip lead

Semiconductors

1 PIC16F1459-I/P microcontroller programmed with 1500520A.hex, DIP-20 (IC1)
1 23LCV1024-I/SN static RAM, SOIC-8 (IC2) [RS Components 803-2181]
1 MCP1703-5002E/DB 5V ultra-low quiescent current regulator, SOT-23 (REG1)
  [RS Components 669-4890]
2 NTR4101PT1G P-channel MOSFETs, SOT-23 (Q1,Q2) [RS Components 688-9152]
1 BC337 NPN transistor (Q3)
1 TSOP4136 IR receiver (IRR1) [Jaycar ZD1953]
1 5mm IR LED (LED1)
1 3mm red LED (LED2)
1 IN5819 1A schottky diode (D1)
1 1N4148 signal diode (D2)

Capacitors

1 100µF 16V low-leakage (LL) PC electrolytic
2 10µF 16V PC electrolytic
3 1µF 16V X7R SMD ceramic, 3216/1206 size
3 100nF MKT polyester

Resistors (all 1/4W 1% metal film)

2 100kΩ 1 47kΩ 3 1kΩ 1 150Ω 1 47Ω
1 10kΩ mini top-adjust trimpot (5mm pin spacing) (VR1)

Extra parts for Jaycar version

1 70 x 135 x 24mm remote control case [Jaycar HB5610]
1 double-sided PCB coded 15005201, 63.5 x 86mm
4 4G x 6mm self-tapping screws

Extra parts for Altronics version

1 68 x 130 x 25mm remote control case [Altronics H0342 (grey) or H0343 (black)]
1 double-sided PCB coded 15005202, 58.5 x 86mm
4 4G x 9mm self-tapping screws
4 5mm long untapped spacers (or M3 tapped spacers drilled out to 3mm)

ballpoint pen. The indicator LED lights, and you then press the button you wish to record a sequence for. The indicator LED flashes in acknowledgement.

The *IR Remote Control Assistant* is then ready to record a series of infrared codes from one or more infrared remote controls. Ensure that these are aimed at the infrared receiver on the *Assistant* as you press each button to broadcast the required codes.

Recording does not start until a remote control signal is received. That way, on playback, the code sequence begins straight away. Any pushbutton (S1-S8) can be pressed to end the recording. Further sequences can be stored by pressing the Mode switch again and using a different pushbutton switch (S1-S8) for each new recording.

At the start of recording, the memory allocated for that pushbutton switch is cleared, ready for a fresh recording. That means that the new recording overwrites any previous recording for that pushbutton switch.

Note that when the *IR Remote Control Assistant* is first placed in the record mode, record mode will end after ten seconds if one of the S1-S8 switches are not pressed within that time. Similarly, after record mode is initiated and a switch is pressed, it will abort if an infrared code is not received within ten seconds.

If you want to clear the memory for one switch without making a new recording, press and hold the mode switch and then press and hold the switch for the memory to be cleared and hold both for ten seconds. The acknowledge LED will initially flash out the pushbutton number (from 1 to 8) before clearing the memory associated with that switch.

Another method of clearing an individual memory is to press and release the Mode switch and then press the switch associated with the memory you want to clear. The memory is first cleared, and then the *IR Remote Control Assistant* waits for the receipt of an infrared code. Press any switch to end the recording. The memory will stay cleared since no IR code was received.

Hints and tips

You can record just about any infrared code sequence, but be aware that sequences could get out of synchronisation if you are not careful.

For example, if you program the unit to change from one source to another, the source you select might depend on what source was selected originally.

Also, if one of the receivers misses a code during playback, the following codes could have no effect or the wrong effect.

So you will need to position the transmitter LED in a location where all the receivers will pick it up reliably before playing back a complex sequence, and avoid moving the unit too much during playback or blocking the IR signals.

Quick instructions

Modes

There are three modes: Playback, Record and Erase. Playback is the default mode, and the unit is normally in this mode. Record mode is invoked when the Mode switch is pressed and released, after which the indicator LED (LED2) lights. It will automatically return to Playback mode unless a recording is started within 10 seconds.

Bulk erase

Full erasure is performed by pressing and holding the Mode switch alone for 10 seconds.

Individual sequence erase

Press and hold in the Mode switch (S9), then while holding that, press and hold in the pushbutton switch (S1-S8) required for memory erasure. Keep pressing both pushbuttons for 10s until the indicator LED (LED2) flashes out the switch number. Release the switches; the selected sequence has been cleared. LED should now only flash momentarily when that pushbutton is pressed.

Recording a sequence

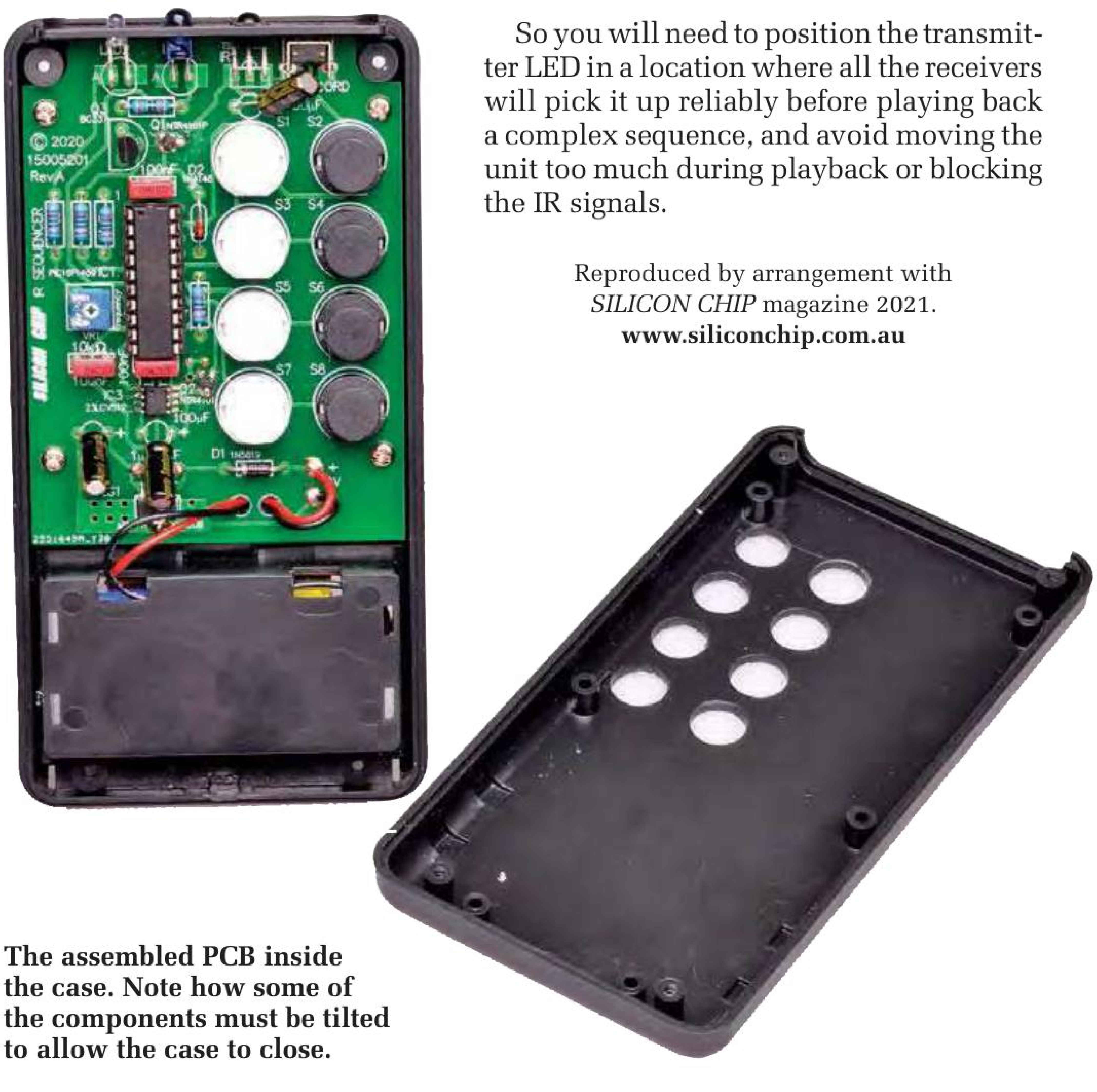
Place the Infrared Remote Control Assistant near the audiovisual equipment with the front end facing toward you. Press the Mode switch (S9) and release. The indicator LED will light. Press the pushbutton (S1-S8) required for the recording. The indicator will flash off and then on again.

Point the audiovisual remote control(s) toward the audiovisual equipment, making sure it also faces the infrared receiver on the Assistant. Start the sequence by pressing a remote control button for the operation first required within ten seconds. Continue to run through the sequence using the remote control to perform the tasks. The indicator will flash at the infrared encoding rate.

Press any pushbutton (S1-S8) to end the recording.

Sequence playback

Playback mode is the default mode, and in this mode, the indicator LED is off. Point the Infrared Remote Control Assistant toward the audiovisual equipment, then press the required switch (S1-S8). The recorded sequence will be reproduced via the onboard infrared LED.



The assembled PCB inside the case. Note how some of the components must be tilted to allow the case to close.

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Touchscreen Wide-range RCL Box

Part 2 – by Tim Blythman

Last month, we described our new *Touchscreen RCL Box*, a compact device that lets you quickly and easily select various resistance, capacitance and inductance values for prototyping and testing. Now we're going to go over the construction, testing and operating procedures. It uses mostly SMD parts, but they're all easy to work with.

In part one, we described how the RCL box works and listed its features and specifications. We also explained how it's built using a *Micromite V3 LCD BackPack* with a touchscreen and two new boards. Now, without further ado, let's start putting it together.

The Micromite itself

You will of course have to build a *Micromite V3 BackPack* with its accompanying 3.5-inch LCD touchscreen module to control the whole shebang. If you haven't already done so, refer to the article in the August 2020 issue – the PCB is available from the *PE PCB Service*, code 07106191.

There is one variation from the original design to note: we used female headers (ie, header sockets) on the back of the *BackPack* PCB to connect to the two other boards used in this project.

So when building the *BackPack*, it's probably a good idea to leave the external I/O and power/serial headers off initially, and fit them later, after you've built the other board.

There's also not much point in mounting the LCD yet. Fit the headers and test that the Micromite connects to the LCD, but don't install the mounting hardware at this stage.

Note that any 'optional' components fitted to the *BackPack* may interfere with the *RCL Box* operation if they share pins; these should be removed if already fitted.

Construction

We suggest that you carefully follow these instructions and build the boards in the order given, or you may find it a bit tricky.

While none of the parts are tiny, you should avail yourself of the usual set of SMT tools, including a fine-pointed, temperature adjustable soldering iron, tweezers, magnifier, solder flux and braid (wick).

Some flux removal solution or even isopropyl alcohol will be handy to clean up any excess flux. In general, more flux is better than not enough! The consequence of this is that the PCBs are left with a messy residue unless cleaned.

Since both boards have mostly components only on one side, they are well suited to reflow soldering. See our articles on building a *Reflow Oven* from April and May 2021.

The design effectively crams four PCBs into the UB3 Jiffy box, so once finished, space will be tight. Therefore, as you progress through the assembly steps, be careful of components standing higher than needed.

In particular, the relays should protrude from the board no more than 7mm; use the parts we have specified (which are around 5mm tall) or check the data sheet of alternative parts before ordering.

Naturally, positioning of the parts is critical for correct operation; if any of the resistors, capacitors or inductors are mixed up then the software won't be able to produce the correct values.

Resistor PCB

We'll start by building the resistor PCB which is coded 04104201 and measures 115×58mm. Its PCB overlay diagram (Fig.3) has been repeated from last month to help you during the assembly.

First, check that you have the correct PCB; the two main boards look very similar. For all the components, we suggest the following process.

Apply a small amount of flux to the pads and hold the component in place with tweezers. Add a small amount of solder to the iron and apply the iron to one lead.

For the larger relays, you may be able to hold them in place with a well-placed finger; their larger body will present less risk of being burnt. Once the component is flat, square and centred, solder the other pin(s).

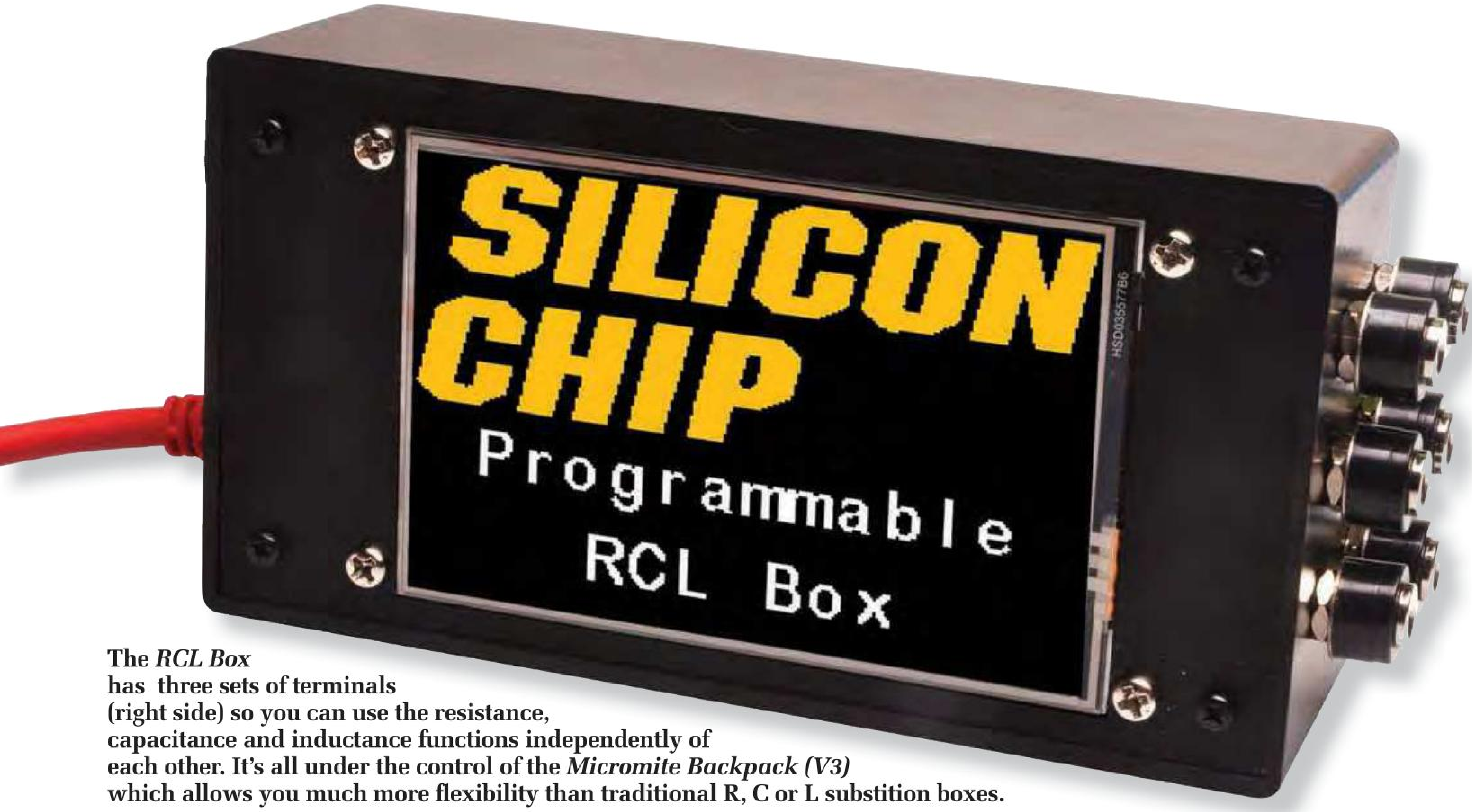
Start with the resistors. Apart from one 10kΩ resistor near the Micromite header, they are all down the centre of the board. We suggest you start at one end and work your way along, ensuring that the value printed on the part matches the silkscreen.

We have repeated the relevant section from last month's parts list for the expected SMD component markings (Table 1).

You should be able to confirm their resistances, even after they are soldered, as they are connected to the (absent) relays at one end, ensuring that their measured values are not distorted by being connected to other components.

There are two 100nF capacitors; they are interchangeable and non-polarised. Ensure they are fitted accurately, as there is not much space around them once installed.

The two ICs have the finest pitch footprints on the PCB (although they aren't very close by SMD standards). It is vital to ensure that the pin 1 dot lines up with the silkscreen. If you cannot see it, pin 1 is also closest to the 100nF capacitor.



The *RCL Box* has three sets of terminals (right side) so you can use the resistance, capacitance and inductance functions independently of each other. It's all under the control of the *Micromite Backpack (V3)* which allows you much more flexibility than traditional R, C or L substition boxes.

Proceed with the ICs as for the other parts, but do not be concerned if a solder bridge forms, as long as the part is aligned correctly. Finish soldering the remaining pins and once the part is secure, use solder braid to carefully remove any excess from one side at a time.

Before you start to add the higher-profile relays, now is a good time to clean up any flux residue according to the instructions on your flux cleaning solution.

There are 14 relays to be fitted, all with their pin 1 markers facing the outside of the PCB. You can confirm this from the silkscreen and also the fact that the pin 1 pad is square instead of rounded. Check your progress against our photos.

Our relays also have a stripe printed on their tops which should match the stripe printed on the PCB silkscreen.

Leave RLY12 and RLY13 until last; they are oriented differently and have more space around them; this gives you better access to RLY10 and RLY11's pins when fitting those parts.

The spacing is quite tight, but the same techniques apply as for the other components. Using a fine-pointed soldering iron, come in almost perpendicular to the PCB so as not to burn and damage adjacent relays. The pins on the relays are at a generous 0.1in (2.54mm) pitch.

Do not add the Micromite headers yet. If you are keen, you might like to run some jumper wires from a Micromite to test the resistor PCB in isolation, although you will naturally need the software installed to do this (as described below).

Capacitor/inductor PCB

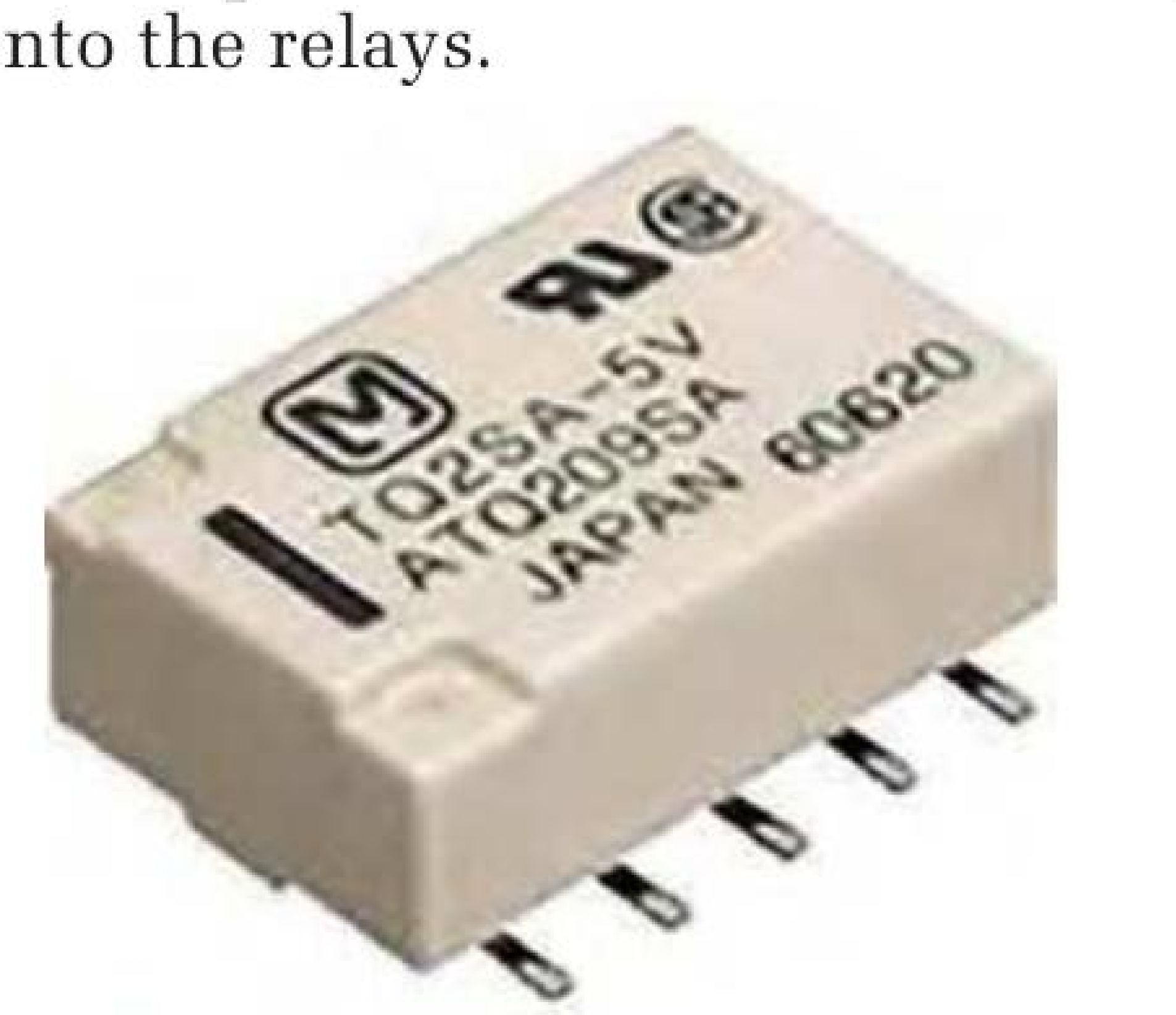
Well recruits, this is what you have been training for. Not only are there 16 relays on this side of the PCB, but many of the components also don't have any markings. Take care not to mix them up. But you should find that the process is much the same as for the resistor PCB.

Start with the capacitors, checking the component value as you go. If you have a capacitance meter, you can use it to double-check that the correct parts have been fitted.

As well as the output capacitors, there are two 100nF parts for bypassing the ICs and a single 10kΩ resistor to fit. As for the resistor PCB, the two ICs have the closest pin spacings. Note that pin 1 on both is closest to the Micromite header.

Following on from this, fit all the inductors except the 3.3mH type. It is larger and can be fitted last, even after the relays.

With all the low-profile parts fitted, clean up excess flux before moving onto the relays.



The low-profile Panasonic TQ2SA-5V relays we used are not commonly available, but they are in stock at Digi-Key and Mouser.

If you have any doubts, now is the time to test the part values, as fitting the relays will make it more difficult to do so.

Proceed with the relays as you did for the resistor board. Patience will definitely help!

Do take note of the orientation markings; most of the relays face the same direction, but the two mounted at right angles face towards each other. We suggest fitting RLY24 and RLY30 before the remainder, as they have the smallest clearances to adjacent components.

Finally, fit the 3.3mH inductor. It has the largest pads and so may need more heat. It's best to apply a thin smear of flux paste to its pads before placing it. When finished, clean up any remaining flux residue.

Mechanical assembly

While the boards we supply are both covered with a solder mask layer, providing a degree of insulation if the boards are laid flat against each other, you should not rely on this.

The solder mask appears durable, but is thin and will not resist much vibration or chafing, and it can even come from the factory with a few holes (especially around vias).

So cover the back of one of the boards with Kapton (or a similar polyimide) tape, except for around the Micromite headers and the four mounting holes.

While CON1, CON2 and CON3 appear to pass through the board, the tape can sit against the back of these; this will help to insulate their pins from the other board. We've used

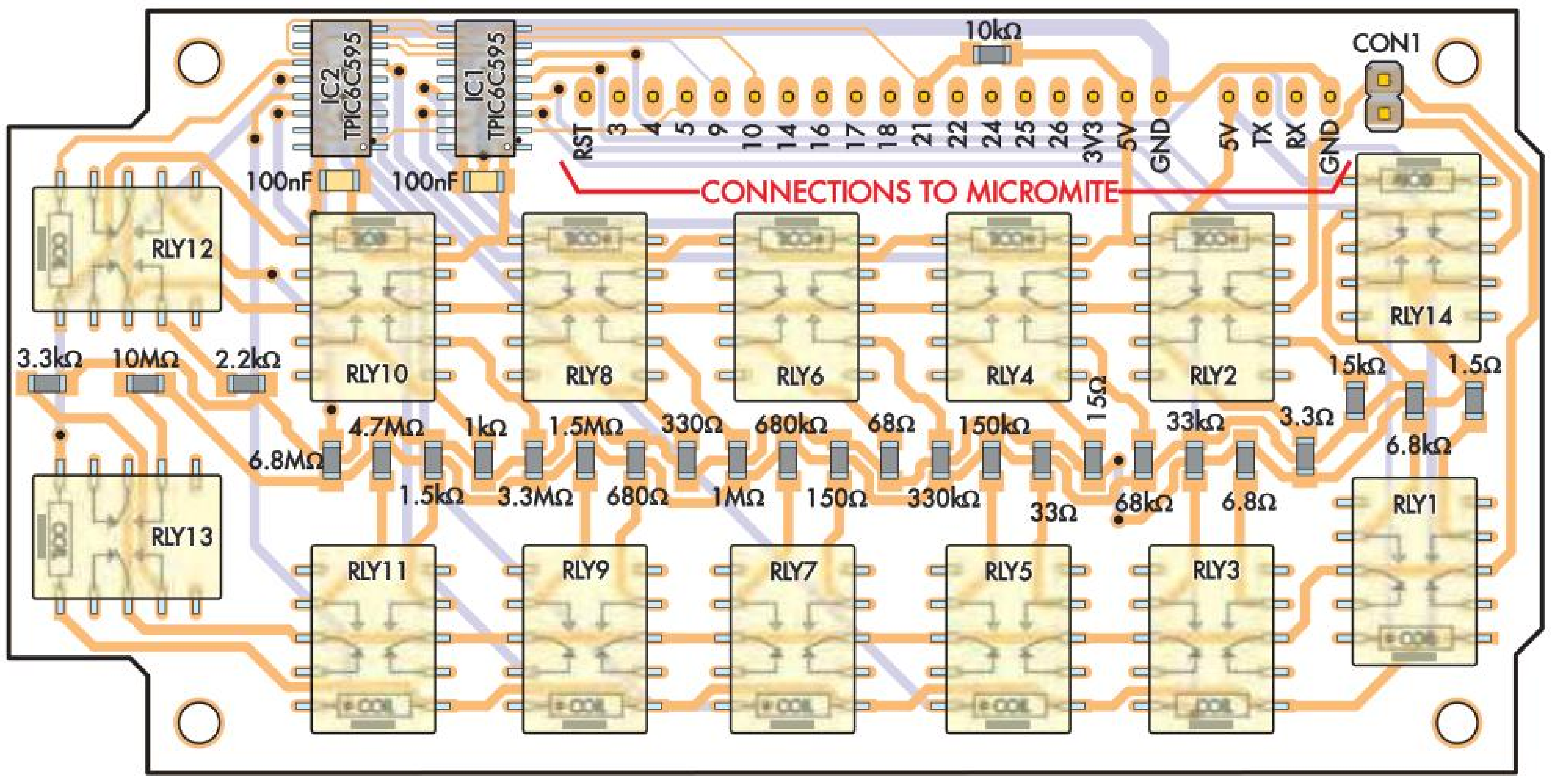
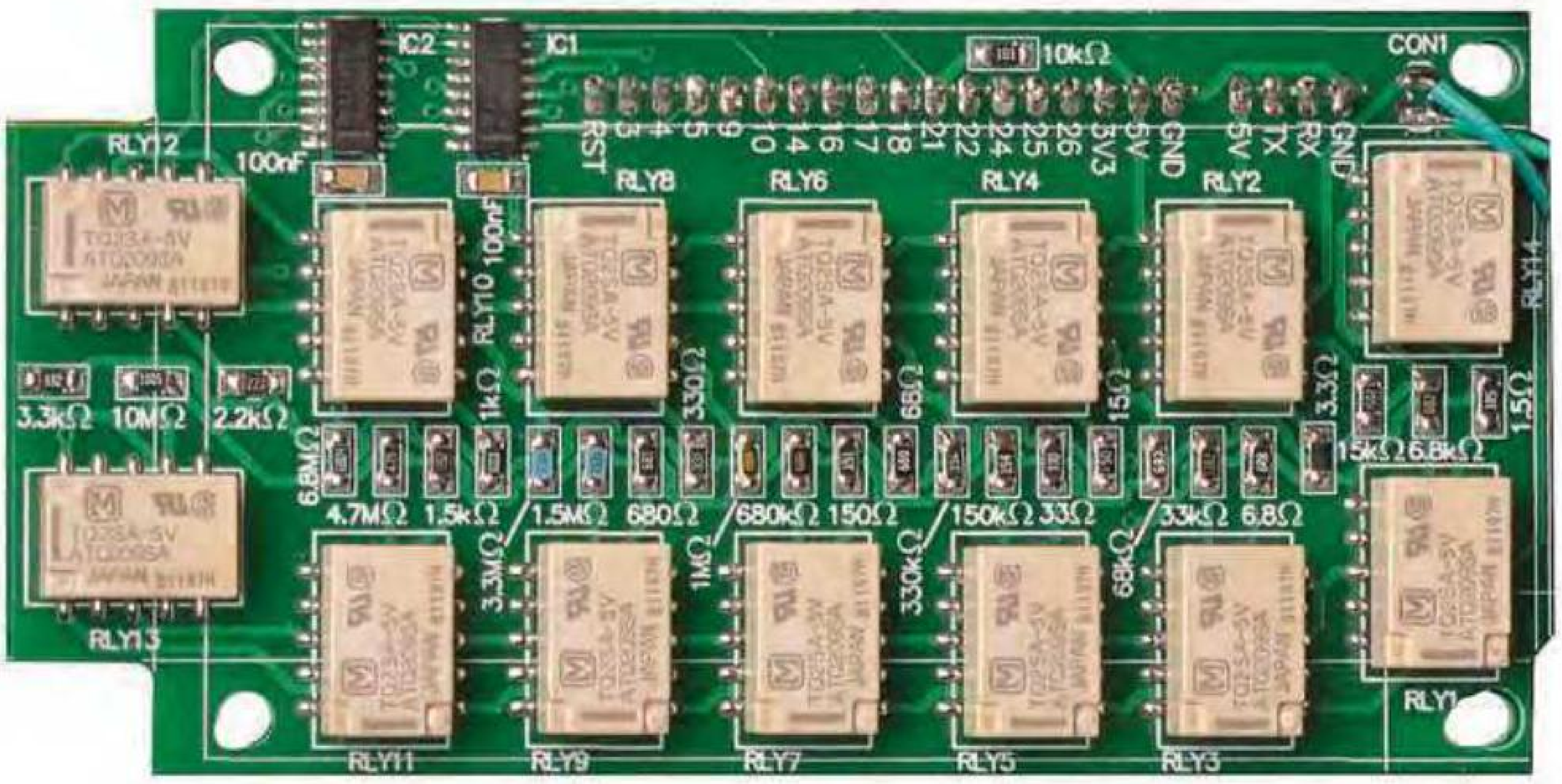

IC2 TPIC6C595
IC1 TPIC6C595
10kΩ
CON1
RST 3 4 5 9 10 14 16 17 18 21 22 24 25 26 3V3 5V GND 5V TX RX GND
CONNECTIONS TO MICROMITE
100nF
100nF
RLY12
RLY10
RLY8
RLY6
RLY4
RLY2
RLY14
3.3kΩ
10MΩ
2.2kΩ
15kΩ
1.5Ω
4.7MΩ
1kΩ
1.5MΩ
330Ω
680kΩ
68Ω
150kΩ
15Ω
33kΩ
3.3Ω
6.8MΩ
6.8kΩ
1.5kΩ
3.3MΩ
680Ω
1MΩ
150Ω
330kΩ
33Ω
68kΩ
6.8Ω
RLY1
RLY13
RLY11
RLY9
RLY7
RLY5
RLY3

Fig.3: the PCB overlay diagram for the resistor board, reproduced from last month. Be careful to orient the relays correctly, as shown here, and add the parts in the order stated in the text to make your life easier. If you have a magnifier, you can read the value codes on the individual resistors.



through-hole pads here to provide more mechanical strength as surface-mounting pads are more easily torn off the PCB.

Assuming you have built the *Micromite V3 BackPack* with LCD as described above, fit the 18-way and 4-way female headers on its back side.

Remember that the *Micromite BackPack* usually has male headers in these positions.

Rather than using multiple threaded spacers with machine screws front and back, we used a different technique for the board stack.

Mount the LCD to the front panel/lid piece using four 32mm-long M3 machine screws, with 1mm nylon washers to separate the acrylic panel from the LCD and the 12mm threaded spacers generally used with the *BackPack*, to secure the machine screws to the LCD panel.

Add the *Micromite BackPack* to the stack, then place 9mm tapped or untapped spacers onto the exposed threads. Add the resistor PCB with its relays facing the *BackPack*, then the capacitor/inductor PCB with its relays facing away and then secure the whole lot with four hex nuts.

Although we haven't made the electrical connections yet, you should now have a good idea of the overall size of the PCB stack.

Before soldering anything, you might like to test fit the stack into the Jiffy box. This will let you know how much room there is left. If you've used the 5mm-tall relays we've specified, you should have around 2mm clearance left.

We now need to use a pin header to connect the two PCBs to each other and the *BackPack* headers. To do this, we remove the individual pins from the plastic spacer strip, which you can do using small pliers.

With the boards held together in the stack, simply slot the pins

Resistor Codes (all 1 of each, SMD 1% 3216/1206 size; SMD markings shown)

10MΩ	106 or 1005	6.8MΩ	685 or 6804	4.7MΩ	475 or 4704
3.3MΩ	335 or 3304	1.5MΩ	155 or 1504	1MΩ	105 or 1004
680kΩ	684 or 6803	330kΩ	334 or 3303	150kΩ	154 or 1503
68kΩ	683 or 6802	33kΩ	333 or 3302	15kΩ	153 or 1502
10kΩ	103 or 1002	6.8kΩ	682 or 6801	3.3kΩ	332 or 3301
2.2kΩ	222 or 2201	1.5kΩ	152 or 1501	1kΩ	102 or 1001
680Ω	681 or 680R	330Ω	331 or 330R	150Ω	151 or 150R
68Ω	680 or 68R0	33Ω	330 or 33R0	15Ω	150 or 15R0
6.8Ω	6R8 or 6R80	3.3Ω	3R3 or 3R30	1.5Ω	1R5 or 1R50

Table 1: reproduced from the parts list in the June issue, this shows the codes you can expect to be printed on the SMD resistors.

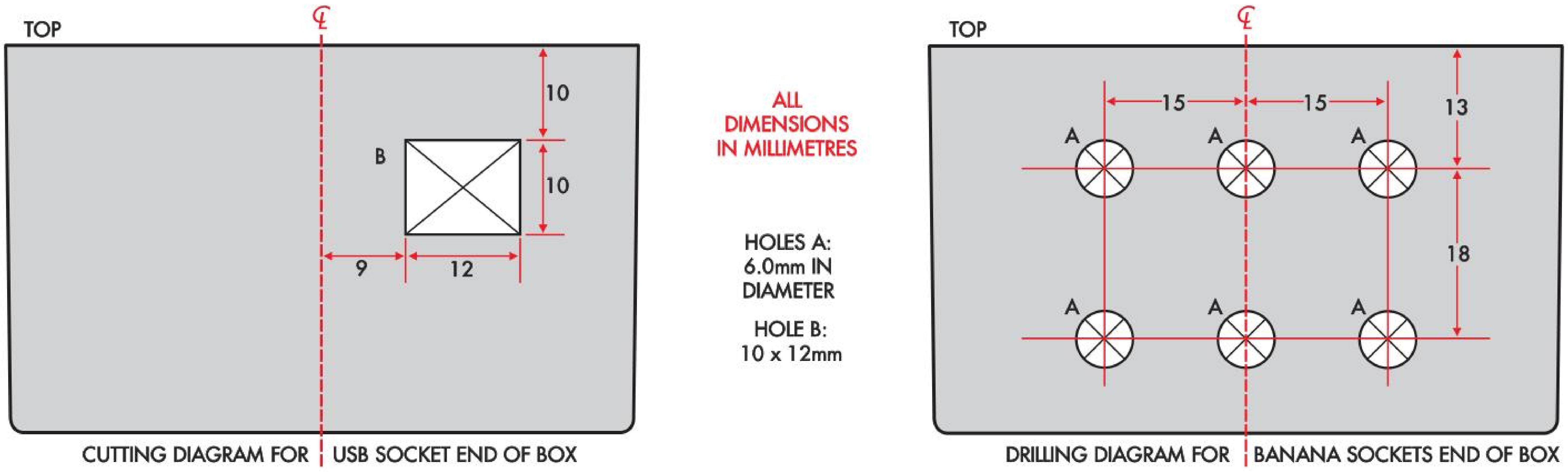

TOP
℄
10
B
10
9
12
CUTTING DIAGRAM FOR USB SOCKET END OF BOX
ALL DIMENSIONS IN MILLIMETRES
HOLES A: 6.0mm IN DIAMETER
HOLE B: 10 x 12mm
TOP
℄
15
15
13
A
A
A
18
A
A
A
DRILLING DIAGRAM FOR BANANA SOCKETS END OF BOX

Fig.5: this shows the location and size of the cut-out for the USB cable, plus the hole locations and sizes for the banana sockets on the opposite side of the case. If you have a USB lead with a large housing, you may need to enlarge its hole. A round (drilled) hole is easier to make, but will not look as neat.

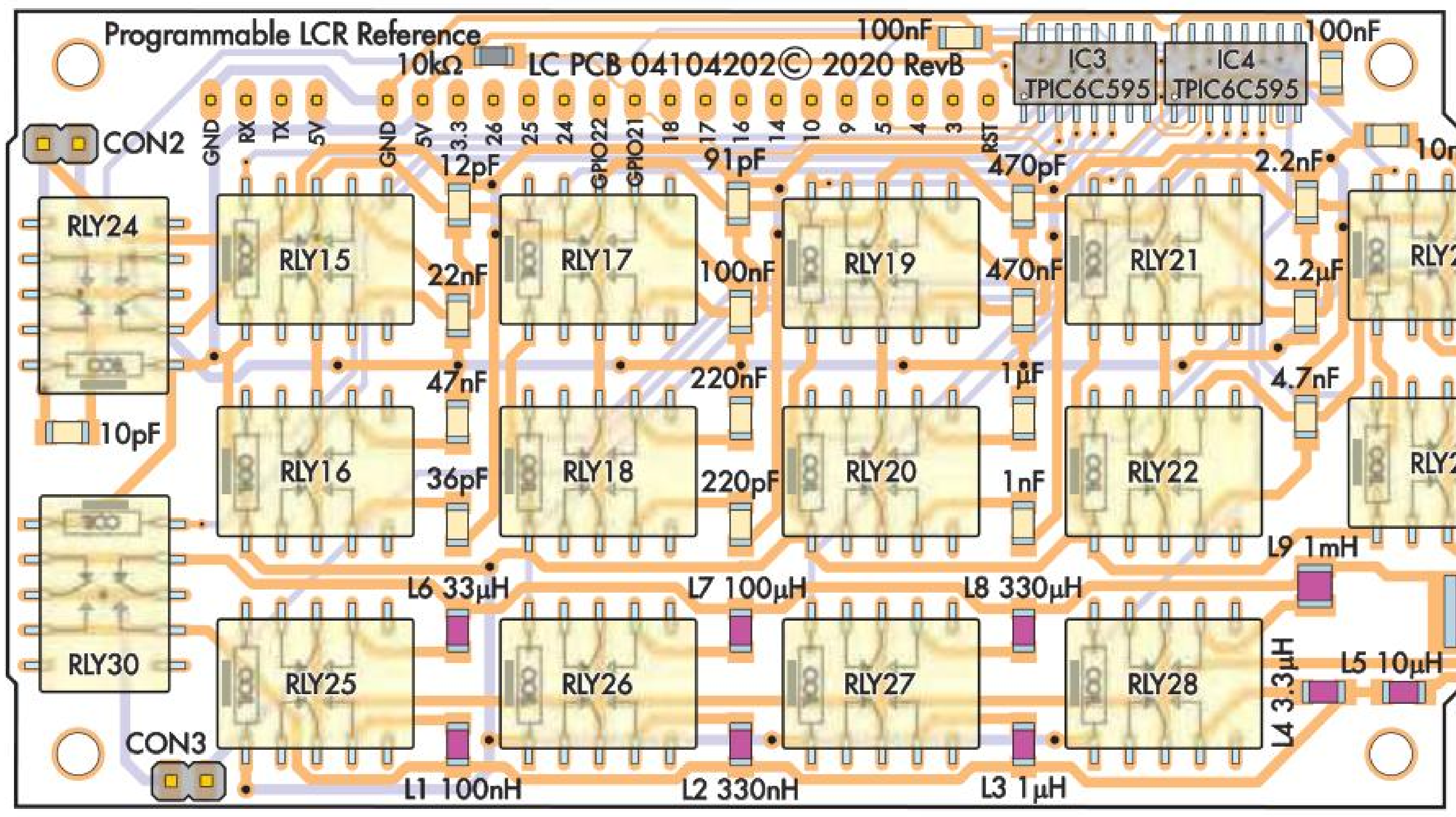
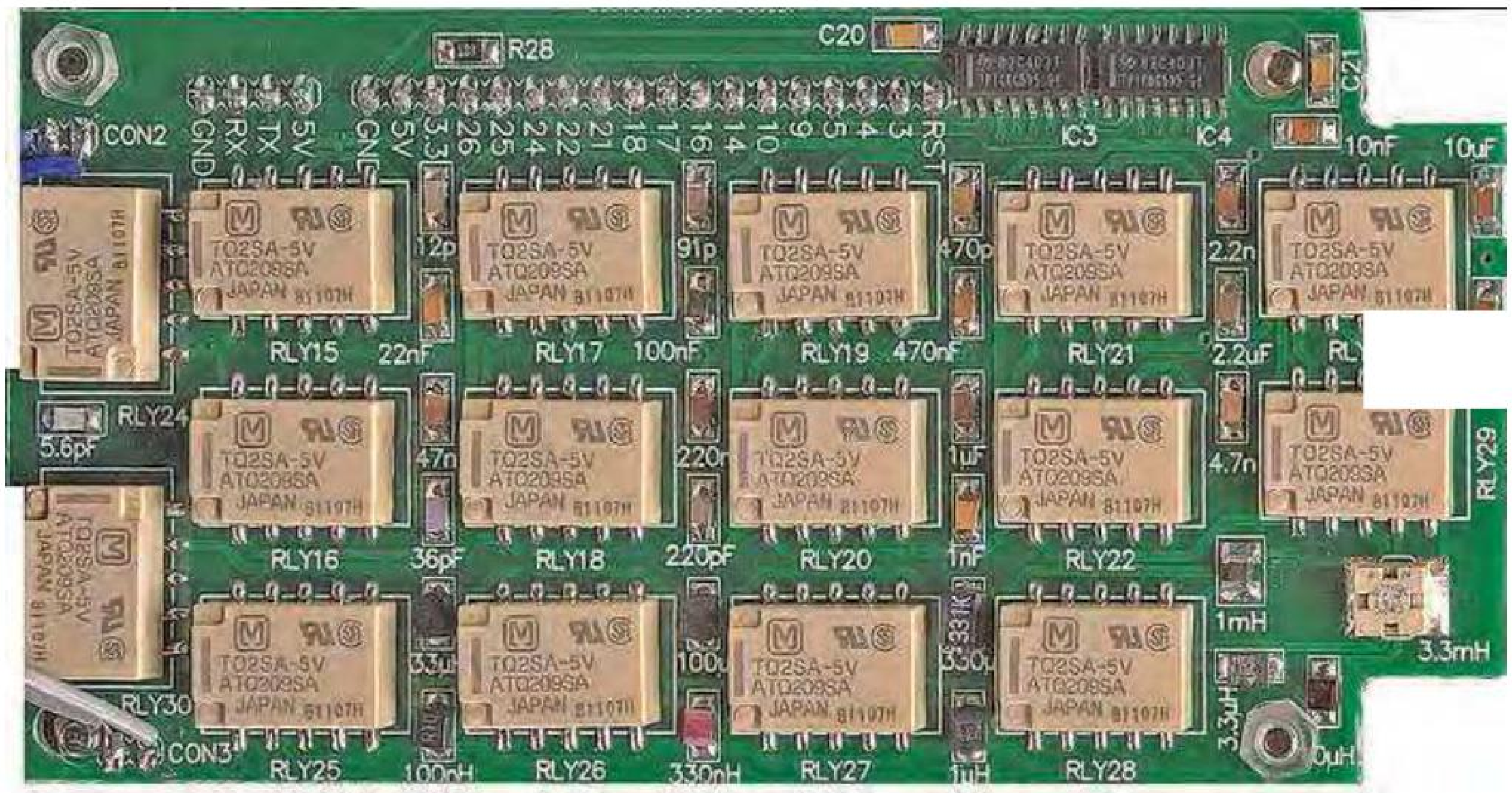
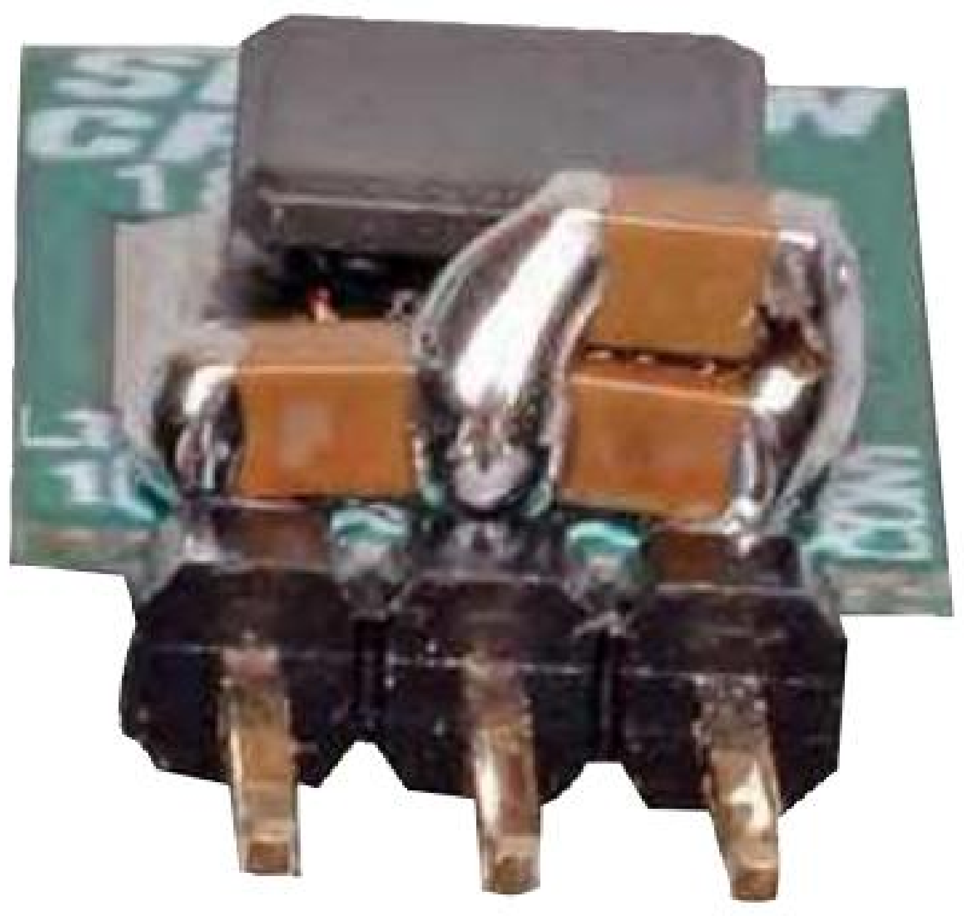

Programmable LCR Reference
10kΩ
LC PCB 04104202© 2020 RevB
100nF
IC3 TPIC6C595
IC4 TPIC6C595
100nF
CON2
GND RX TX 5V GND 5V 3.3 26 25 24 GPIO22 GPIO21 18 17 16 14 10 9 5 4 3 RST
12pF
91pF
470pF
2.2nF
10nF
10µF
RLY24
RLY15
22nF
RLY17
100nF
RLY19
470nF
RLY21
2.2µF
RLY23
47nF
220nF
1µF
4.7nF
4.7µF
10pF
RLY16
36pF
RLY18
220pF
RLY20
1nF
RLY22
RLY29
L9 1mH
L6 33µH
L7 100µH
L8 330µH
L10 3.3mH
RLY30
RLY25
RLY26
RLY27
RLY28
L4 3.3µH
L5 10µH
CON3
L1 100nH
L2 330nH
L3 1µH

Fig.4: the capacitor/inductor board has more relays and some larger components, so it's a bit packed. But if you follow our instructions, you should not find it too difficult. Again, watch the orientation of the relays. The inductors should have printed values but the capacitors won't.





Here's a trick we even see some manufacturers perform; stacking multiple capacitors to achieve a higher capacitance value. In this case, we have combined a pair of 4.7µF parts to replace a single 10uF part. It's not hard to do as long as you don't apply to much heat.

through the PCB holes into the female header on the *Micromite BackPack*, one at a time.

Once you have confirmed that everything will fit together, solder the header pins to the PCBs, ensuring that enough solder is applied to wick down the stack into the bottom PCB of the pair.

This can be assisted by squirting a little flux paste into each hole before inserting the pin.

Alternatively, if you have no plans to remove the PCBs from the *BackPack*, you could omit the female headers and solder male headers directly to the *BackPack*.

Then, after mounting the resistor and capacitor/inductor PCBs, solder the headers to these two PCBs as well.

You may need longer pins to do this, or you may choose to run short lengths of wire between the two boards instead.

USB socket

For our prototype, we simply made a cut-out in the side of the box to allow power to be supplied to the *BackPack* using a standard USB cable with a mini Type-B connector. Its location is shown in Fig.5. This hole will allow most USB-mini plugs to pass through the side of the box and directly into the Micromite's USB socket. It may need to be enlarged if your USB lead has an unusually large plug.

An alternative that we have used on some projects is to fit a DC barrel socket; its wires are run back to the 5V and GND connections. See Fig.6 for how to wire such an arrangement. You will need to solder the wires to the pins on the capacitor/inductor board, as this connects to the header on the *BackPack* board.

Note that such a DC jack must be installed near the lid of the Jiffy box as the PCB extends nearly the full width of the bottom of it. Altronics (P6701) and Jaycar (PP1985) both carry USB-to-DC plug leads made up. Or you could use a regulated plugpack with 5V output and the correct tip polarity, to match the socket wiring.

Banana sockets

You might have noticed that there is not much space in the Jiffy box; thus, we've had to use low-profile banana sockets for the six test connections.

The locations of their mounting holes, on the opposite side to the USB power cut-out, are shown in Fig.5.

Once fitted, the sockets are simply free-wired back to their respective pads on the PCBs. We suggest mounting the sockets in the enclosure first, to test that they do not foul the PCBs.

Once this is done, solder short (5cm) leads to each socket, then solder them to the respective pads on the PCBs. CON1 is for the resistance connections, CON2 for capacitance and CON3 for inductance. The LCD shows their values in this order from top to bottom, so the sockets should be wired accordingly.

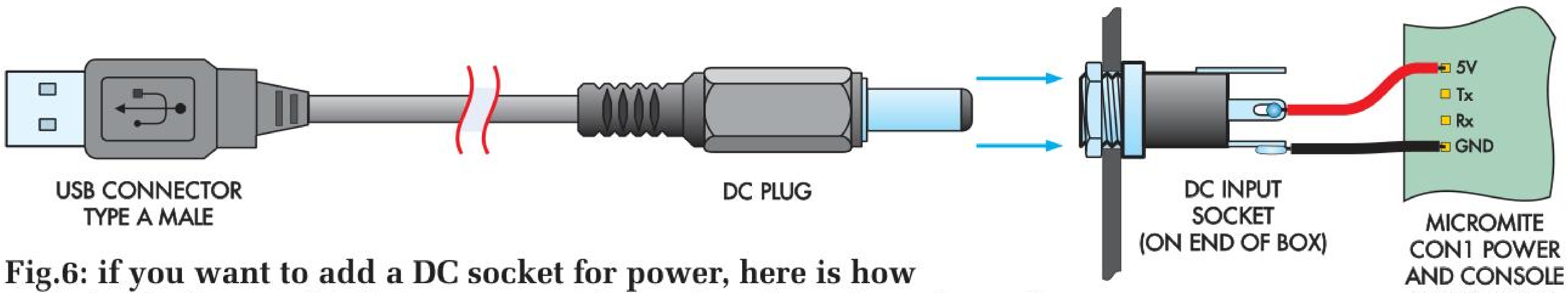
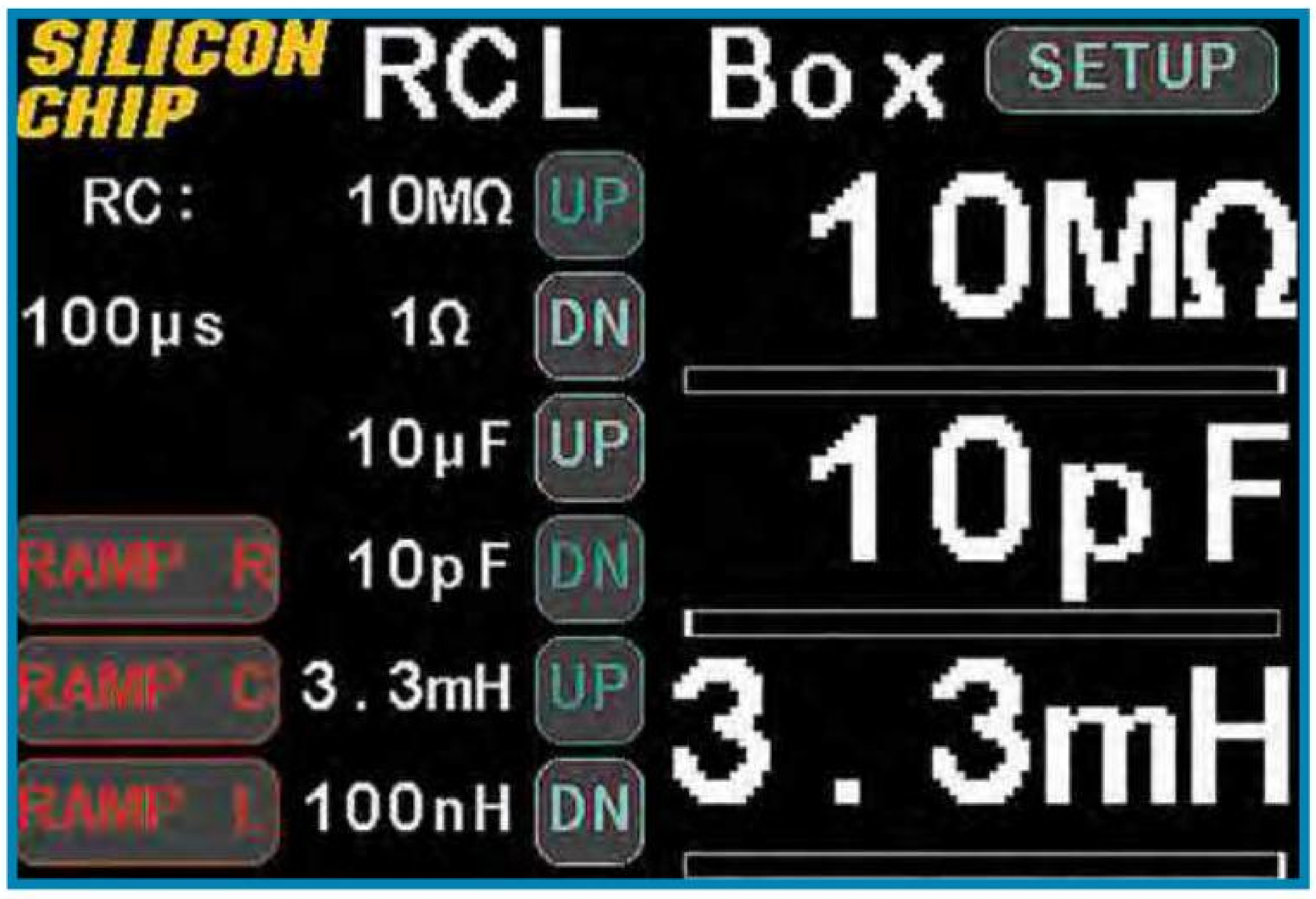
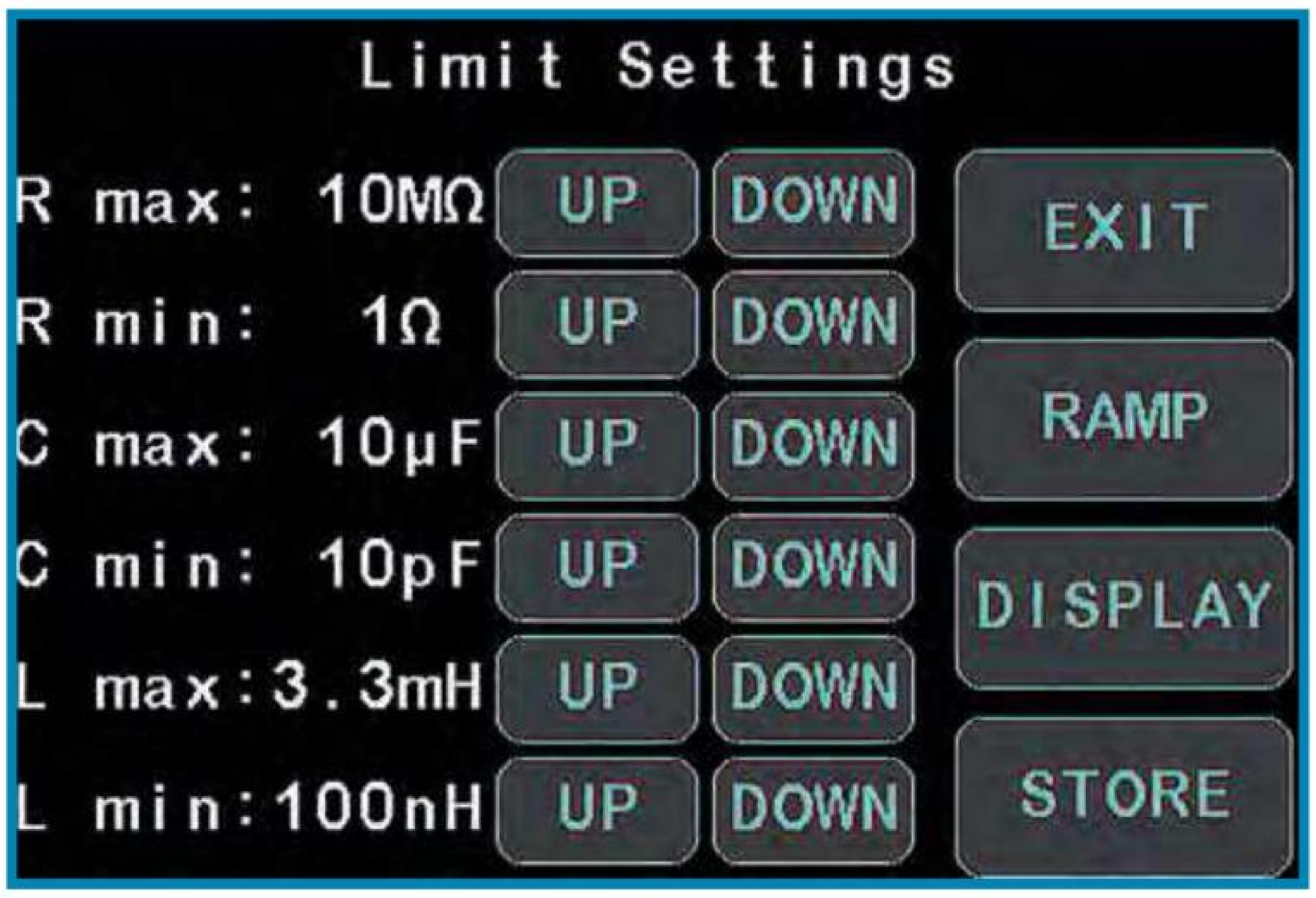

USB CONNECTOR TYPE A MALE
DC PLUG
DC INPUT SOCKET (ON END OF BOX)
5V
Tx
Rx
GND
MICROMITE CON1 POWER AND CONSOLE CONNECTOR

Fig.6: if you want to add a DC socket for power, here is how to do it. But be careful that you mount it in a location where it won't foul the board stack. The USB-to-DC plug lead is a commonly available, pre-assembled part (eg, Altronics P6701; Jaycar PP1985).



Screen1: the larger 3.5-inch display allows a lot of useful information to be displayed by the Micromite. At right are the three output parameters, displayed adjacent to their respective banana sockets. The values can be changed by a simple tap up or down, via a slider or automatically ramped by the software.



Screen2: pressing the SETUP button opens the Limit Settings page. There, Soft limits can be set to avoid non-useful or dangerous test values. Further settings can be found by tapping on the RAMP or DISPLAY buttons, while STORE saves the current setting to non-volatile Flash memory.

You may find it easier to remove the PCBs from the stack while soldering the leads. None of the parts are polarised, so it actually doesn't matter if you swap the wires to the pairs of sockets.

Micromite setup

There are two ways to load the software on the Micromite; the easiest is to simply load the **RCLBOX.HEX** file directly onto the chip using the onboard Microbridge or a PIC programmer such as a PICkit 3 or PICkit 4.

The alternative is first to load the Micromite with MMbasic, then configure it and upload the BASIC source code over the serial terminal.

This is the required approach if you wish to customise the way the *RCL Box* works.

To do this, assuming you have a new Micromite (we're using MMBasic version 5.4.8), first open the **library.bas** file (extracted from the download package for this project, available on the July 2021 page of the *PE* website) and upload it to the Micromite (eg, using MMedit).

Then type 'LIBRARY SAVE' at the Micromite console and press enter. Next, type 'WATCHDOG 1'. After pressing Enter, the Micromite should restart and the screen will clear. The terminal should display:

```
Watchdog timeout
Processor restarted
ILI9488 driver loaded
```

You can then run the command 'GUI TEST LCDPANEL'; you should see circles appearing on the LCD. Press Ctrl-C to end the test.

Next, run 'OPTION TOUCH 7,15' to enable the touch driver. Then run 'GUI CALIBRATE' and complete the calibration sequence.

If you like, you can run 'GUI TEST TOUCH' to confirm that the display and touch panel are working correctly together. Ctrl-C ends this test program too.

At this stage, the display is configured and the main BASIC program can be loaded. Open the **RCL Reference Box.bas** file, send it to the Micromite and run it. The AUTORUN flag is automatically set, so the software will start up when powered in future.

The software as loaded now is the same as what you would get from the HEX file; the remaining steps are settings and configuration within the *Programmable RCL Box*.

Finishing touches

If you have not already done so, now would be a good time to fit the acrylic lid to the display by removing the four machine screws. Place the 1mm spacers over the holes and then thread the machine screws through the acrylic panel and into the tapped spacers.

Note that the acrylic lid piece is not symmetrical; if it appears that the PCBs behind are sticking out the side, you may have it the wrong way around. As a hint, the end of the *Micromite BackPack* with the USB socket goes to the end with the wider-spaced holes.

Slot the stack into the case and secure the lid with the four screws that came with the Jiffy box.

Configuration and use

When powered up, a splash screen appears, followed by the main operating screen (Screen1). This is where the resistance, capacitance and inductance values are controlled.

In a large font along the right-hand side are the currently selected resistance, capacitance and inductance values. There are three ways that these values can be changed.

First, the slider beneath each value can be used to make quick, coarse changes. You should have no trouble picking the exact value needed, but the up and down buttons to their left are better to make fine changes.

To the left of the up and down buttons are the soft limits which can be set. These allow the output values to be restricted if this is desired. Note that the up and down buttons are greyed out when the values are at their soft limits, warning you that you are at the extreme values.

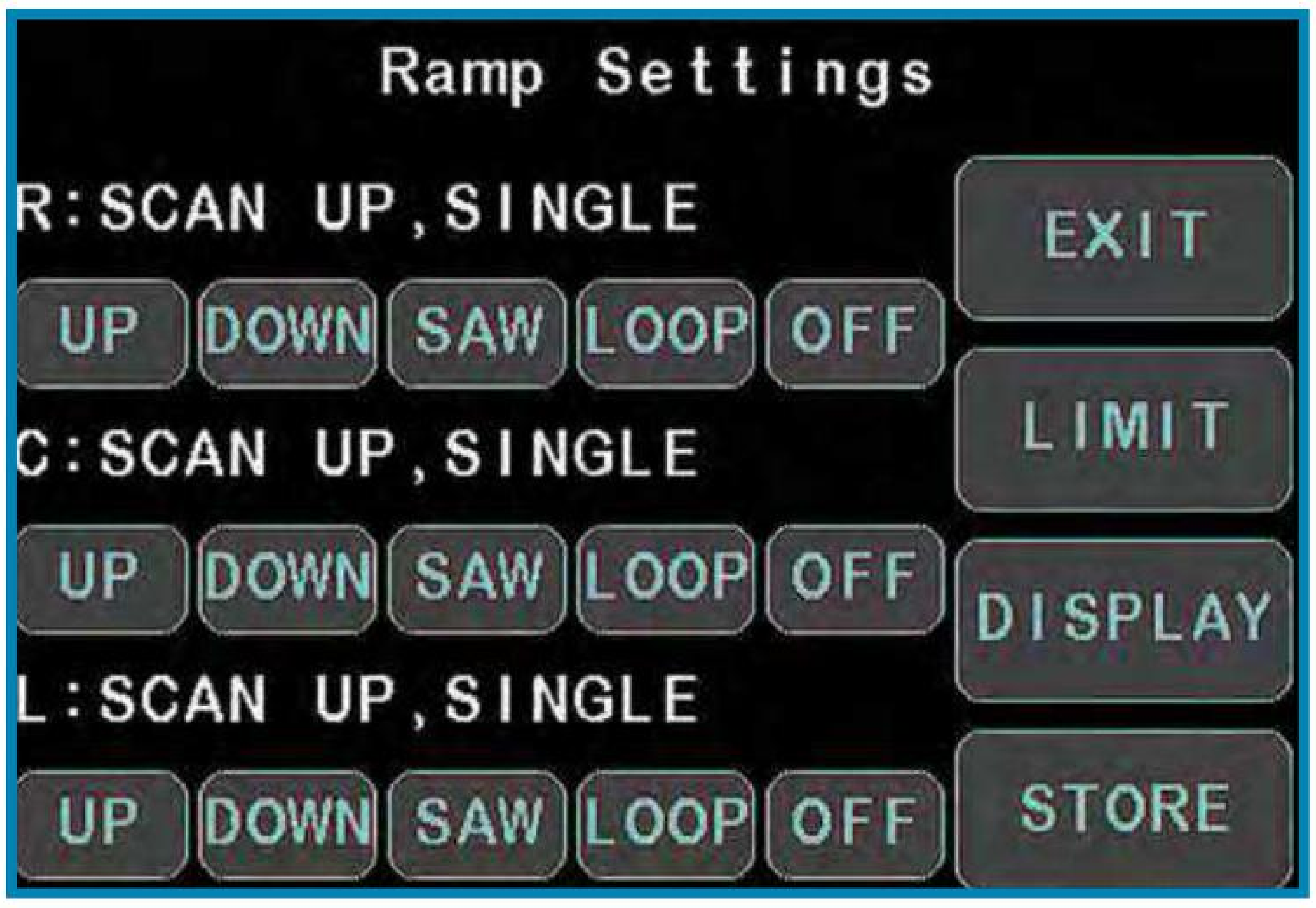
At bottom left are the ramp controls, which can be used to step the outputs automatically. They are red when the ramp is inactive, turning green when activated. The ramps make use of the minimum and maximum soft limits as their range.

Above this is there is a small numerical display, which indicates a characteristic time or frequency based on a selected combination of the currently enabled resistance, capacitance and inductance.

The 'Setup' button at top right changes to the first of three pages for altering settings (Screen2). This allows the soft limits to be altered, with up and down controls for the minimum and maximum values of each range.

Any changed settings are made active immediately, but are not automatically saved to Flash. This is done by the 'Store' button, which ensures that the current settings are saved for use at power-on.

This has been done to minimise wear and tear on the internal Flash memory and also provides an



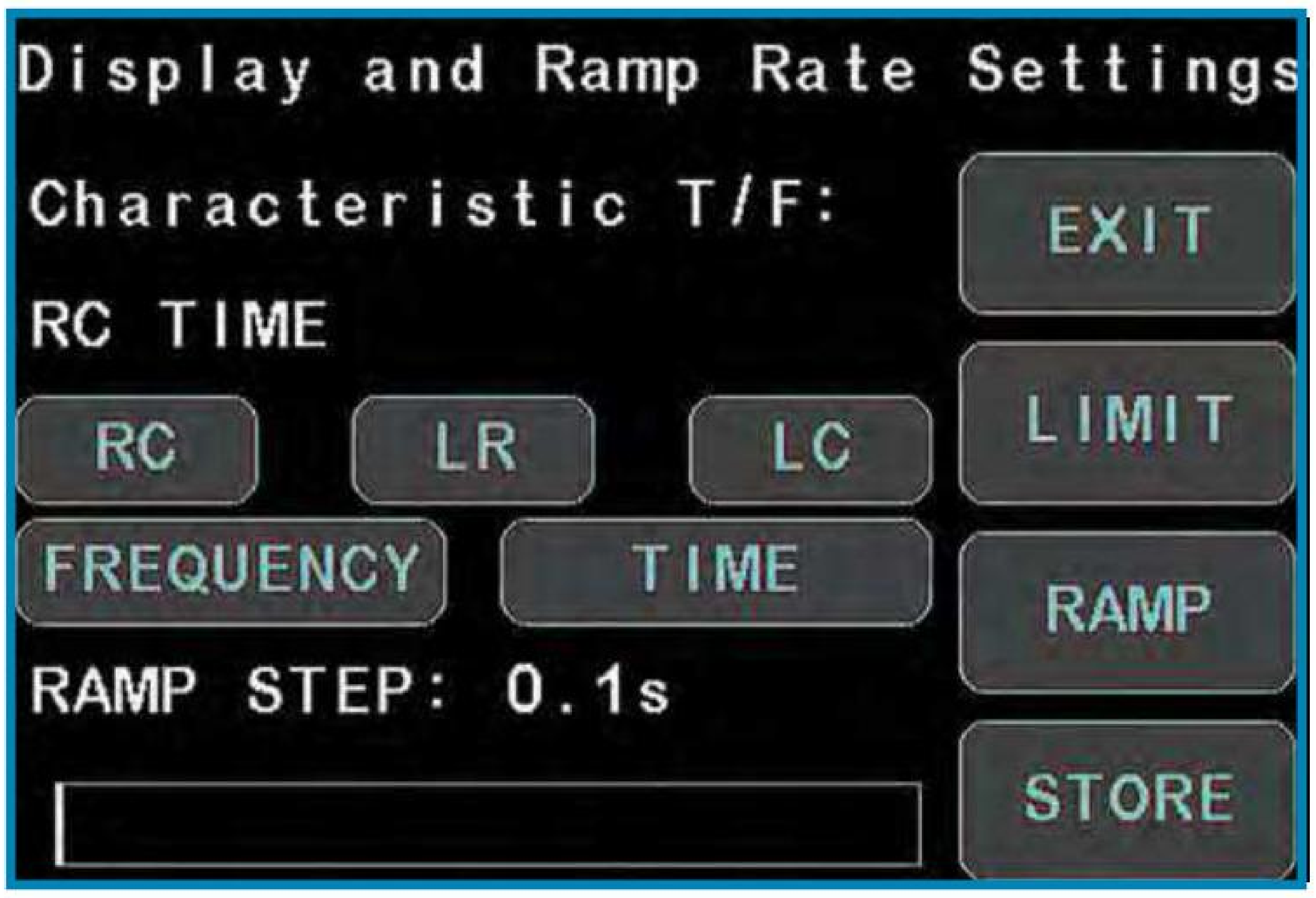
Ramp Settings

R:SCAN UP,SINGLE

C:SCAN UP,SINGLE

L:SCAN UP,SINGLE

Screen3: the RAMP setting page controls the automatic ramp modes. These can be set to up, down or sawtooth, with the option to perform a single or repeated ramp. There are individual settings for resistance, capacitance and inductance; thus, you can ramp resistance up and capacitance down simultaneously if that is what is needed.



Display and Ramp Rate Settings

Characteristic T/F:

RC TIME

RAMP STEP: 0.1s

Screen4: the DISPLAY page contains the setting for what characteristic time/frequency should be displayed. A choice of either LC, RC or LR combinations can be chosen, with either time constant or frequency being available as further options. The step time for the ramp modes is also chosen by the slider along the bottom of the page.

opportunity for settings to be tested before saving. If you change the settings to something you don't like, then a simple power cycle will reload the last saved values.

Pressing the 'Exit' button returns to the main control page; note that this and some of the other buttons are present on more than one page to allow ease of navigation.

Pressing the 'Ramp' button opens a page for the settings that control the ramp modes (Screen3); a setting for ramp rate is found on the 'Display' page (Screen4).

There are settings to ramp up, down and in a sawtooth pattern ('Saw'), which alternates between up and down.

The ramps can also be set to loop continuously or not ('Off'). The current setting is displayed in a friendlier fashion above the buttons.

If an output is set to ramp up but not loop, it will ramp up to its maximum and then stop. The next time it is started, it will reset to the minimum and ramp up again. This simplifies repeated tests.

The Display page includes the ramp step time; this can be set from 0.1s to 10s in 0.1s intervals by dragging the slider along the bottom of the page.

The final setting at the top of the Display page is the characteristic time/frequency, which controls what is displayed at the top left of the main page. There is a choice of RC, LR or LC combinations, and the characteristic time constant or frequency can be selected.

Of course, these may not match the operation of your circuit as not all circuits operate at their characteristic time constant, but they are a useful thing that the processing power of the Micromite can add.

BASIC code

In case you wish to delve deeper into the operation of the BASIC program, we'll explain a little bit about how it works.

After a handful of OPTIONs are set near the start, several colour values are defined. If you wish to change the feel of the interface, changing these colours is an easy way to do it.

The output values and relay images list the available values in pairs of arrays. One contains a list of the output values as floating-point numbers; these are the RVALUE, CVALUE and LVALUE variables.

The RIMAGES, CIMAGES and LIMAGES arrays contain nominal 16-bit values which describe the bit pattern which is output to the relays.

In the case of the capacitor and inductor images, these are combined with a simple addition to allow the data to be combined for simultaneous latching.

There would be little point changing the image arrays unless you reworked the circuit itself, but you could add extra resistance values by using combinations of more values than what we have.

Note that these lines are very close to BASIC's 255 character limit, so edit them with care.

Most of the remaining code is to create the user interface. While we often complain about how bloated software can be at times, it's nice to have an easy-to-use set of controls; it's just unfortunate that it takes so much code to do so!

The five subroutines starting with RELAYINIT perform the interfacing to the shift registers.

If, for example, you were interested in interfacing these boards to another microcontroller such as an Arduino or even a Raspberry Pi, then we suggest looking at these subroutines to understand how to interface and check the schematic to know what pins need to be connected.

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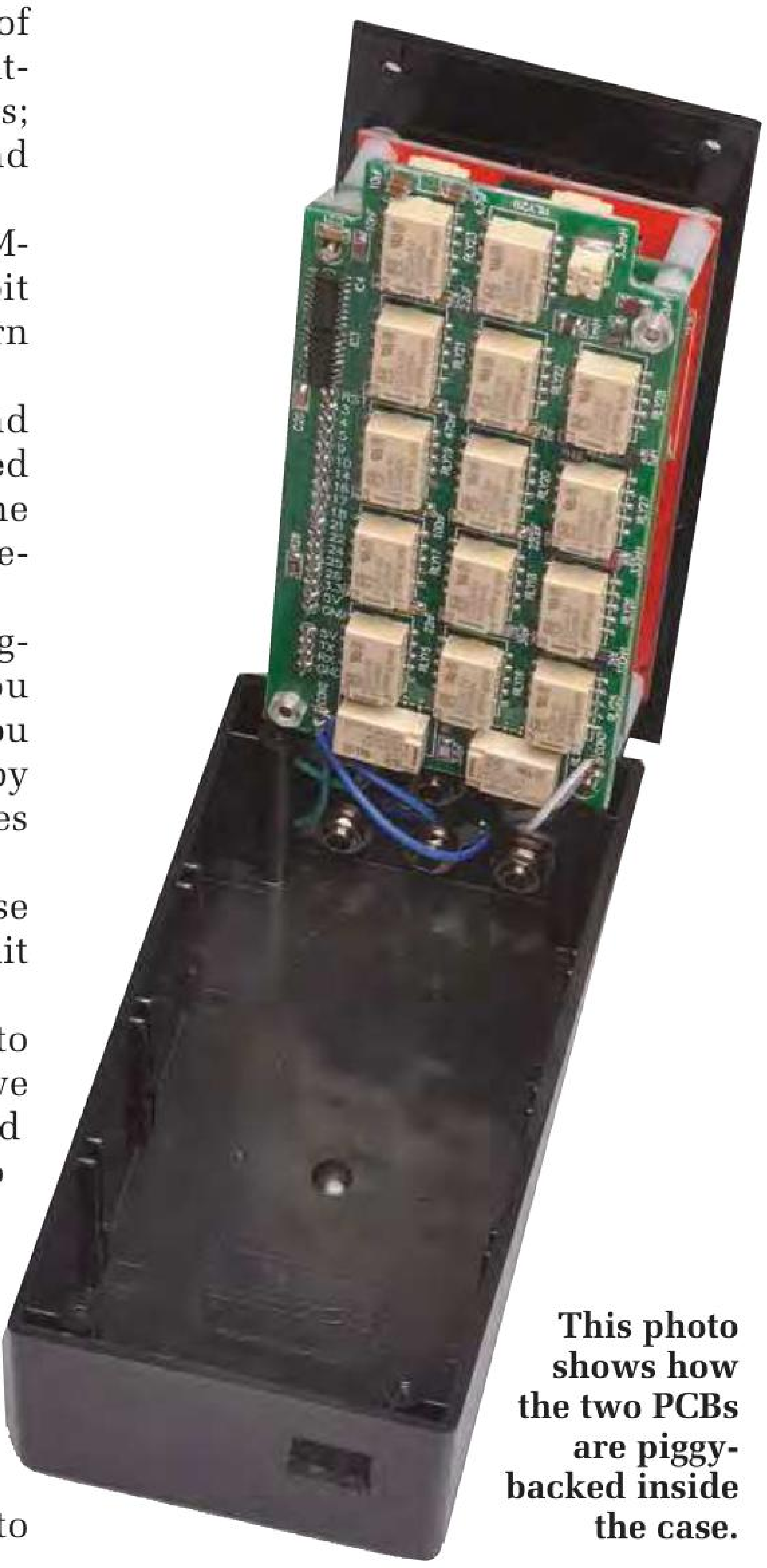


This photo shows how the two PCBs are piggybacked inside the case.

Practically Speaking

Hands-on techniques for turning ideas into projects – by Jake Rothman

Restoring old equipment – Part 4

This month, we conclude the series on restoring the Leak Stereo 30, looking at the pre and power amplfers. Plus, we will suggest some interesting upgrades to the circuit design, and look at useful component substitutions.

Testing the power amps

The Leak Stereo 30 power amplifier is shown in Fig.37. Two words of warning, the power transistor heatsinks are live (connected to the collector). One brush with an earthed lead will destroy them. Ensure the volume control is at minimum in case the preamp is oscillating or has a leaky coupling capacitor. Note that the conductive 'silver' washers (Fig.38) for mounting the output transistors are made from solder or a soft metal to aid deformation for thermal conductivity.

Offset voltage

Like all old transistor amplifiers, the output is biased to sit mid-way at around half the power supply voltage. This has to be checked before the output coupling capacitor (C37) and should be around –20V.

Quiescent current

All discrete class AB amplifiers have a quiescent current pre-set adjustment P7 (see Fig.29). If the current is too low, crossover distortion occurs; if too high, you get thermal runaway and destruction of the amplifier. It is a fiddly fine-spot, best set up with a low-distortion 300Hz sinewave, notch filter, a pair of ears and a 'scope to monitor the residual. If you don't have the equipment for such a set-up, a current from 15 to 20mA is about right.

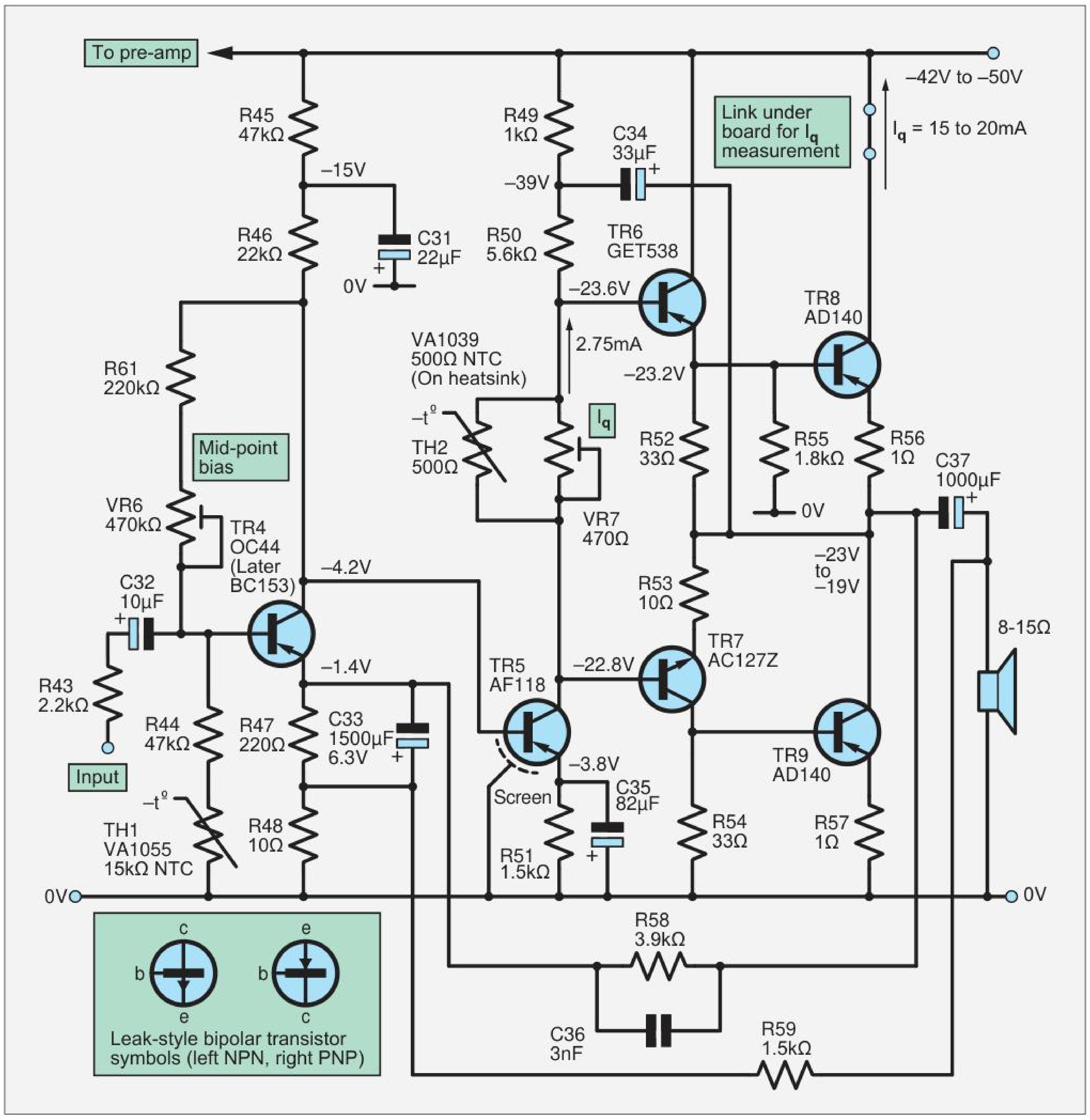

To pre-amp
R45
47kΩ
–15V
R46
22kΩ
C31
22µF
0V
R49
1kΩ
–39V
C34
33µF
R50
5.6kΩ
Link under board for I_q measurement
–42V to –50V
I_q = 15 to 20mA
TR6
GET538
–23.6V
2.75mA
VA1039
500Ω NTC
(On heatsink)
–23.2V
TR8
AD140
R61
220kΩ
Mid-point bias
–t°
TH2
500Ω
I_q
R52
33Ω
R55
1.8kΩ
R56
1Ω
C37
1000µF
0V
VR6
470kΩ
TR4
OC44
(Later
BC153)
VR7
470Ω
–23V
to
–19V
C32
10µF
–4.2V
R53
10Ω
8-15Ω
R43
2.2kΩ
–1.4V
TR5
AF118
–22.8V
TR7
AC127Z
R44
47kΩ
R47
220Ω
C33
1500µF
6.3V
TR9
AD140
Input
–3.8V
Screen
C35
82µF
–t°
TH1
VA1055
15kΩ NTC
R48
10Ω
R51
1.5kΩ
R54
33Ω
R57
1Ω
0V
0V
R58
3.9kΩ
c
e
b
b
e
c
Leak-style bipolar transistor symbols (left NPN, right PNP)
C36
3nF
R59
1.5kΩ

Fig.37. Leak Stereo 30 power amplifier circuit. The original Leak diagrams use an early transistor symbol shown in the inset – this is for a bipolar transistor, *not* a FET!

There are links under the PCB for measuring the quiescent or standing current in the output transistors with no signal. However, I found it easier to measure the voltage drop across the 1Ω emitter resistors. It's prudent to set the preset (VR7) to give minimum current before turning on. Here, it's fully clockwise or minimum resistance. I set it using the preset at 25mV corresponding to 25mA. This is assuming the emitter resistors (R56, R57) are 1Ω. After 50 years they are likely to have drifted high. Also, germanium devices exhibit a much greater risk of thermal runaway. They have higher leakage currents than silicon devices and this can increase with age. The driver and output transistors should just be noticeably warm. If they get hot, turn off. Sudden quiescent current increases as the preset is increased must also be watched for. This can be caused by an oxidised preset, faulty driver transistors (TR6, TR7) or high-frequency instability. Also, the current will rise as the amplifier warms up, so trim it back a bit after it's run for 15 minutes.

Replacement transistors

It's worth examining the *PE Transistor Guide* from the May 1966 issue, which contains a list of germanium transistors – it's available for download from the February 2021 page of the PE website. (Pages 4 and 5 are missing – the AC and AF series. If a reader has a complete copy we would like to add them.) Also, Andrew Wylie has a fantastic transistor history site at: **https://bit.ly/pe-ps21-05**

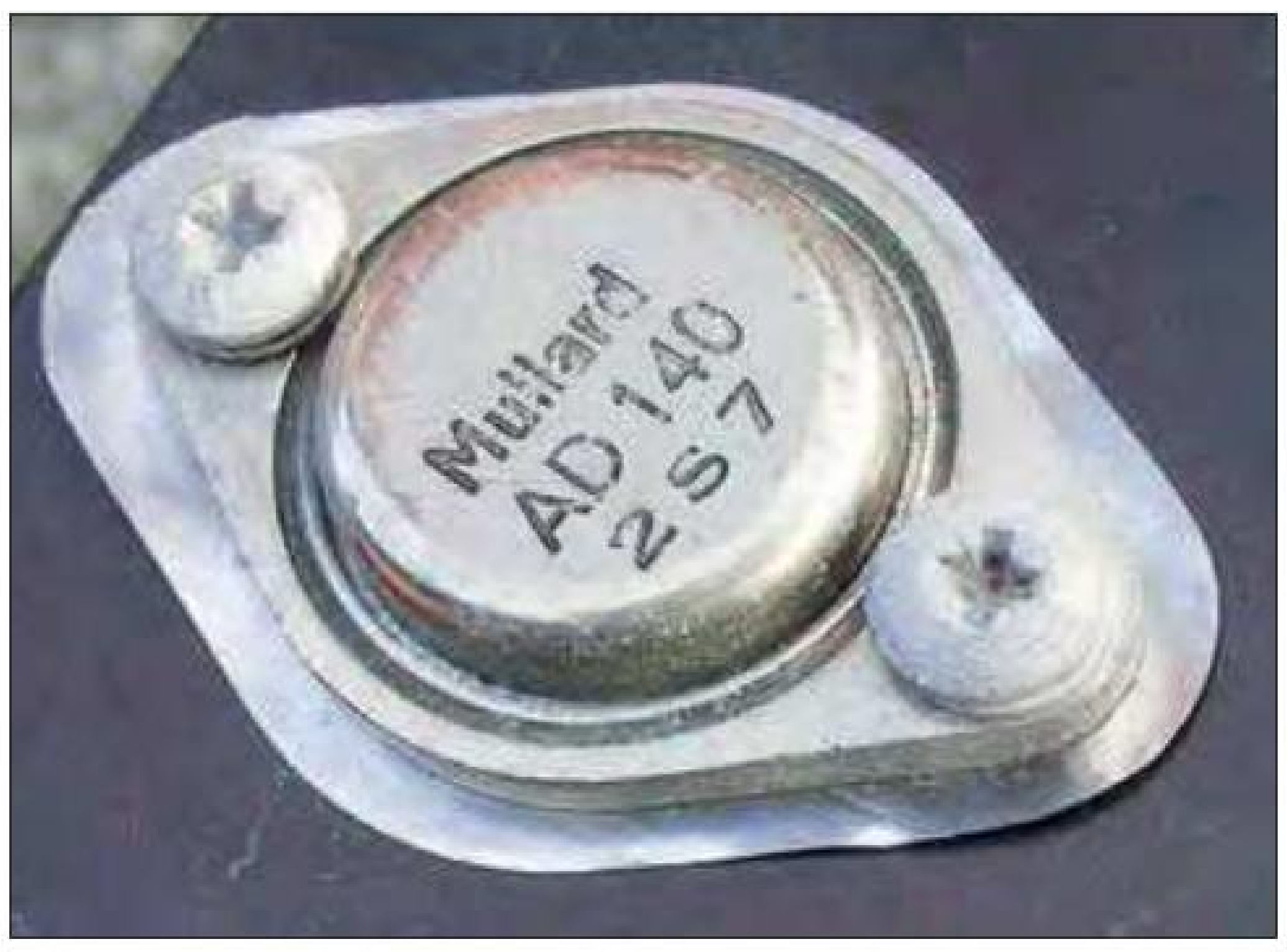

Mullard
AD140
2S7

Fig.38. Mullard AD140 power transistor and heatsink. Note the soft metal washer is electrically conductive, so the heatsinks are 'live'. Is the date indicated by the three-character code?

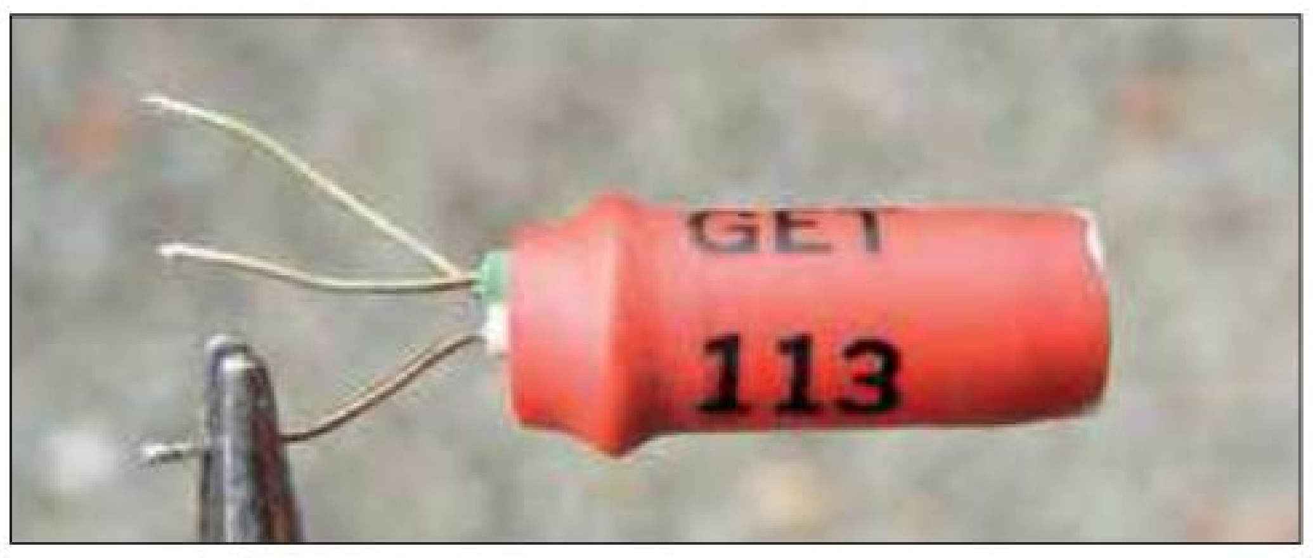
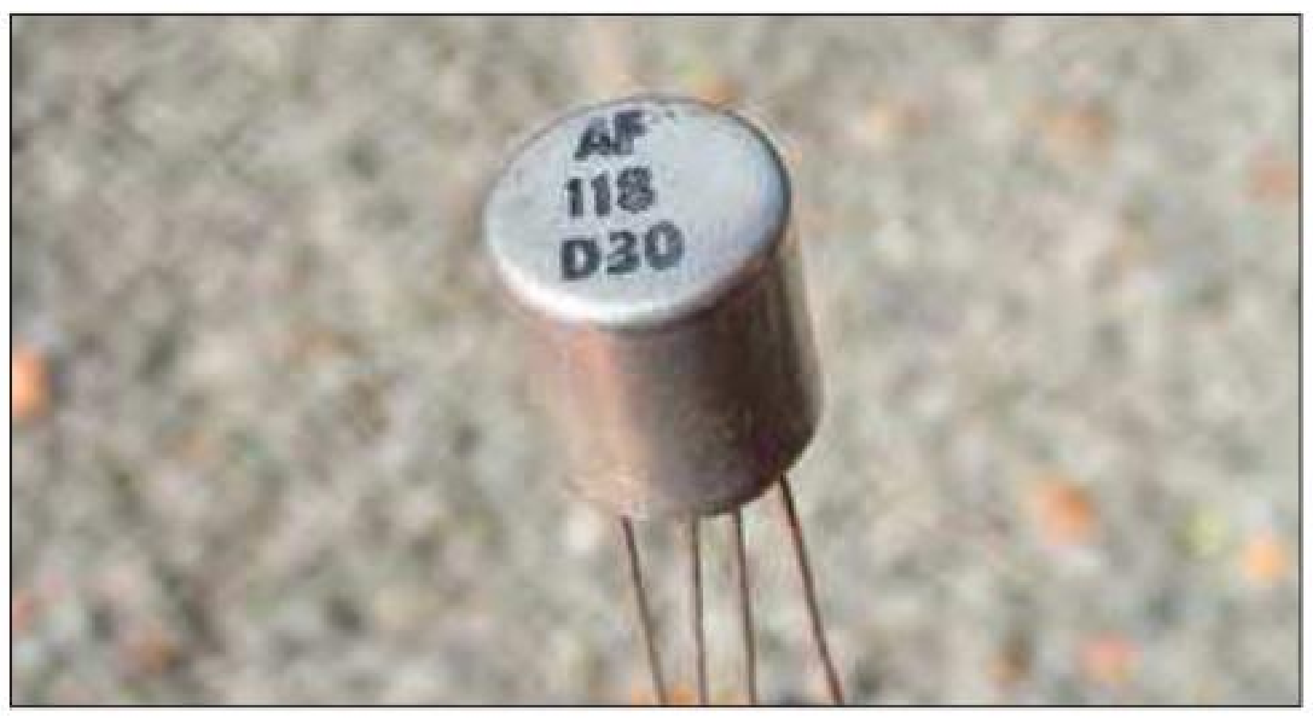


Fig.39. (above) GET113 small-signal transistor; Fig.40. (below) The enigmatic AF118 (TR5) – a rare germanium high-voltage RF transistor. Its data sheet was in the *Siemens 1970-71 Semiconductor Manual*, p.228.



Small signal

It can be hard to find replacements for failed transistors. The preamp transistors (TR1, TR2, TR3) and power amp input transistors (TR4, TR5) can all be directly replaced with silicon types, since the DC bias levels can be adjusted by pre-sets. BC559s or BCY71s (if you want an older-looking type) or other low-noise PNP small-signal example will be fine. The noise will be lower than the original germanium types. I suspect they get leakier and therefore noisier with age. (At 60 years, we may be near the wear-out end of the 'bathtub curve' of germanium transistor useability see: **https://en.wikipedia.org/wiki/Bathtub_curve**). The input transistor AC107 was originally designed for tape heads and is supposed to have a noise factor of 3dB. Even Leak had to buy specially selected ones. I replace these with the NKT214F or 2SA49 devices, which seem to be the lowest-noise germanium transistors I've got. The GET113 (Fig39) is not critical, almost anything rated at 25V will be fine here, such as the AC126 or CV7001. The OC44 is used because it has a 15MHz f_t (upper frequency limited) and fairly low noise, but it is too expensive today. I've substituted germanium Japanese AM radio transistors types 2SA12, 49 or 52 for these. If you want a proper British Mullard transistor, the GET872 is a good-looking substitute.

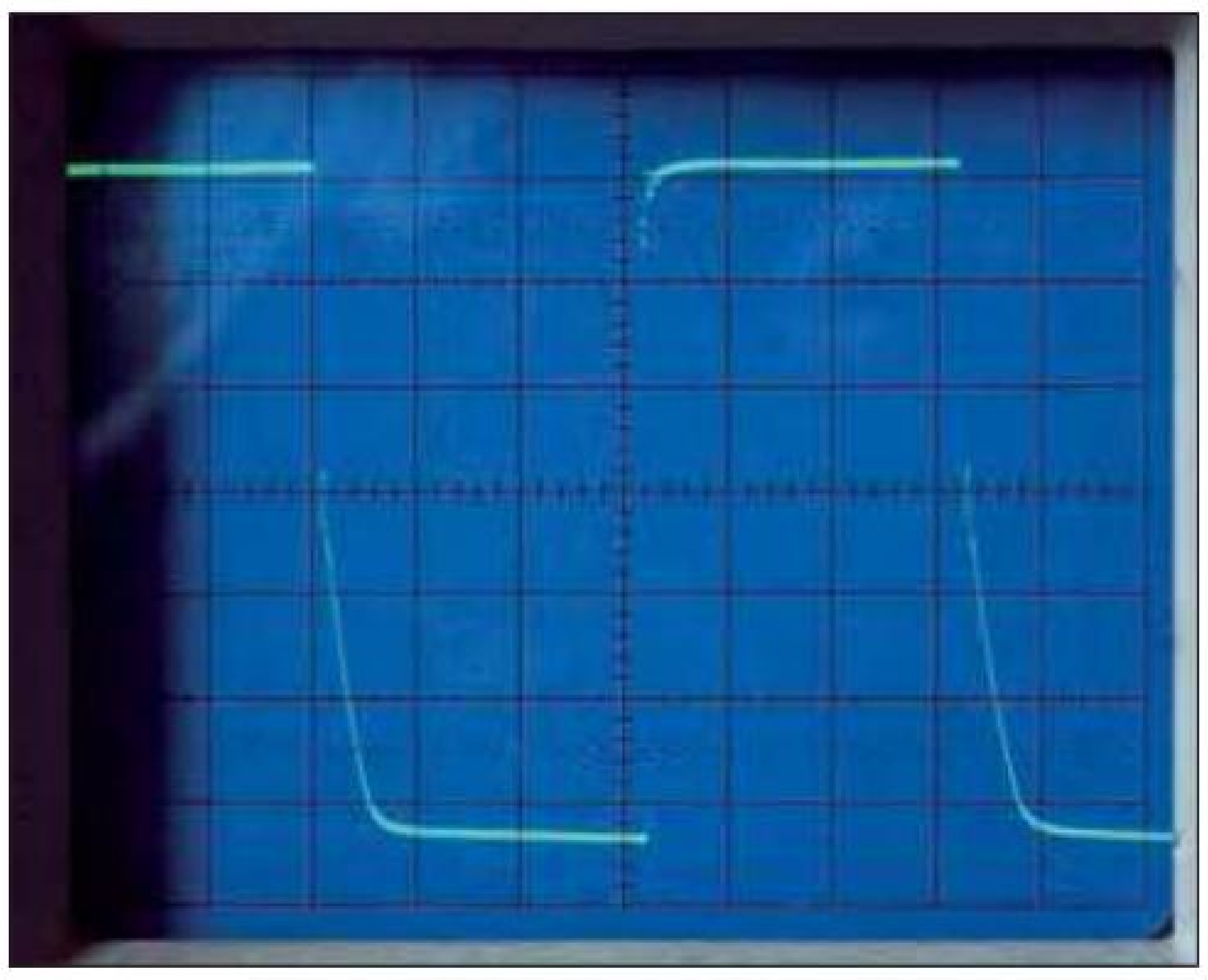


Fig.41. Poor 1kHz square-wave response due to substituting a slow, low-frequency transistor (ASY53) for the AF118, an RF (radio-frequency) transistor (TR5).

Voltage amplifier

TR5, an AF118 (shown in Fig.40), is especially difficult, since it is both a high-voltage (70V), and high-frequency 125MHz alloy diffused or drift-field device. This transistor was one of the first to be designed for the video amplifier in televisions and was used in the 1963 Perdio Portarama black and white TV. (See *Radio and Television Servicing*, 1963-64 issue, p.523, and also **https://bit.ly/pe-pe21-06**). I had to get an AF118 on eBay and it cost £3.95! I tried an ASY51, which had the voltage (60V) but not the bandwidth (1MHz). The amplifier oscillated at first, so I reduced the feedback phase-lead capacitor C36 to 330pF. It worked, but the square-wave response was poor, as shown in Fig.41.

Some Japanese types, such as the 2SA103 and 2SA358 should work, but that would detract from the unit's 'Britishness'. I did try a Mullard ASZ20 40V 40MHz switching transistor (Fig.42) which worked well, but the V_{CE} was 40V, which gives only a small margin. This device and the AF118 use the unusual TO7 case with a fourth lead (S) for the case/screen lead. This package is infamous for internal shorts due to tin-whisker growth. Sometimes banging the unit hard will dislodge them. Disconnecting the screen lead, which isn't needed here except for radio use, also often works as the whiskers grow from the inside of the case. These whiskers can sometimes be electrically fused by connecting all three transistor leads together and discharging a 100µF capacitor charged to 35-50V through to the case, as shown in Fig.43. This dodge is also very useful for old radios. In my case, the AF118 had a base-emitter short, so it couldn't be fixed.

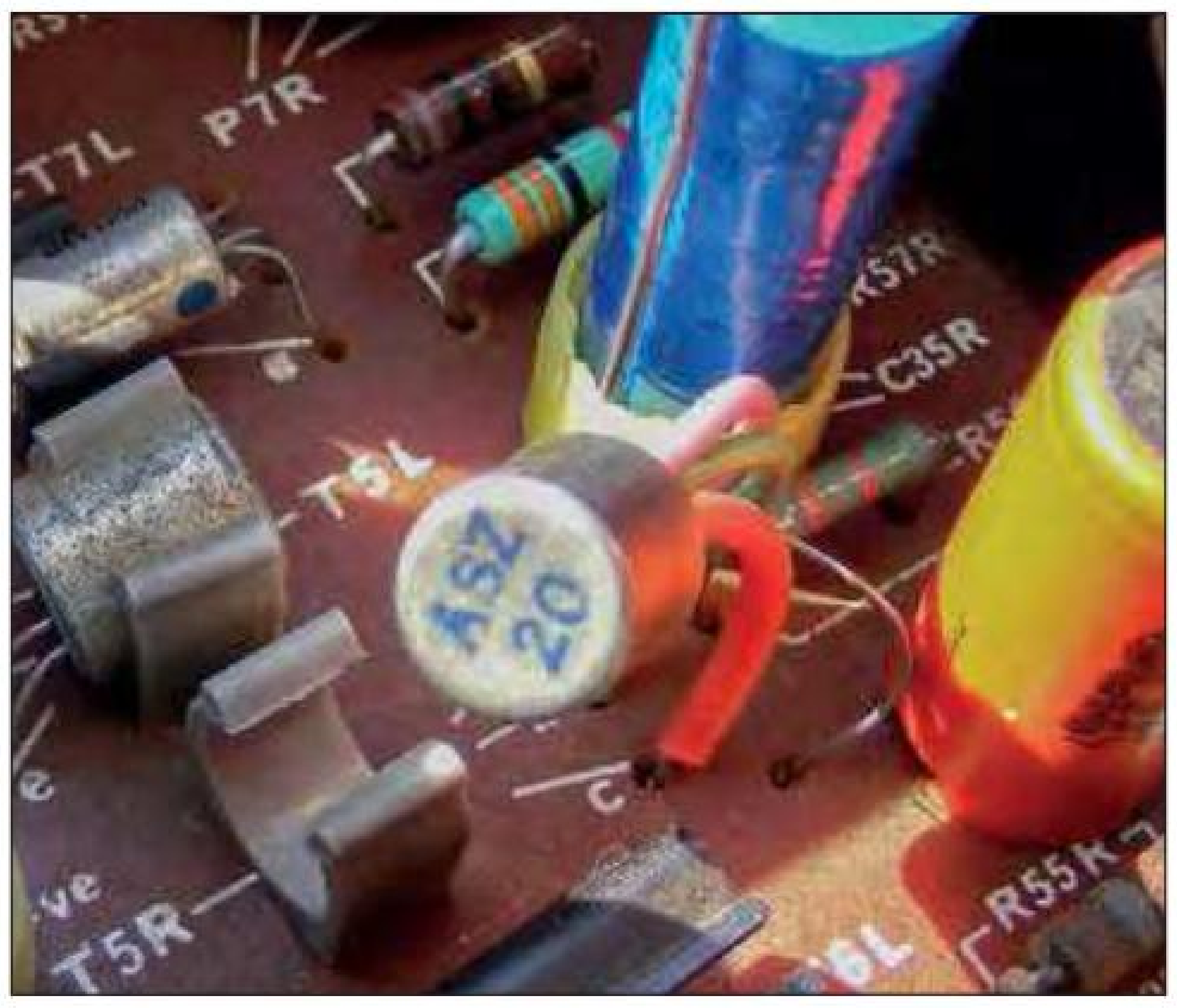


Fig.42. This ASZ20 from Birkett's was the only suitable direct replacement for the AF118; unfortunately, they only had one.

Drivers

The two original output driver transistors (TR6 and TR7, Fig.37) are also practically unobtainable, especially TR7, the NPN device. These are shown in Fig.44. The AC127Z is an NPN small power device specially selected for high voltage (50V V_{ce}) denoted by a 'Z' stamped on the top (Fig.45). A military Texas 2N388A 40V V_{cb} (Fig.46) could be fitted, which is better than an AC127Z and is what Tobey and Dinsdale used. There is a high voltage AC141, the AC141H. The Newmarket NKT717 could also be employed. The 2N35 (Fig.47) was used in the original Lin design, but only rated at 25V.

The GET538 (Fig.48) is not a problem being PNP, and can be replaced by the ACY17, ACY48, NKT227, OC81Z or 2N1377. Note the unique tapped TO5 heatsink arrangement shown in Fig.49. The GET538 seems to be a mini power transistor rated at 1.5A I_c max and is full of copper heatsinking inside. I suspect such a highly rated device was used to allow

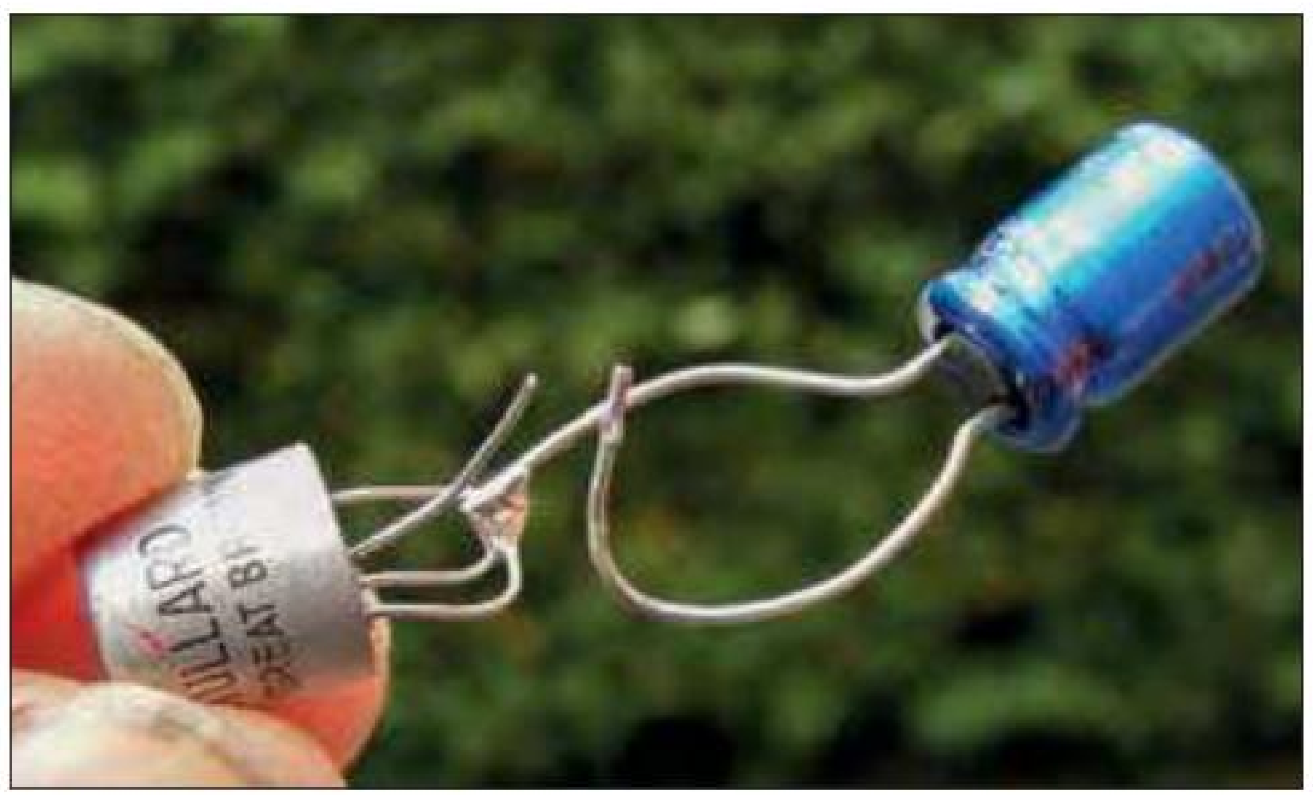


Fig.43. The TO7 tin-whisker problem can often be fixed with a capacitor discharge. This trick has saved many classic radios using AF114/5/6 or 7 and OC170 transistors. It has to be done every five years since the whiskers continue to grow.

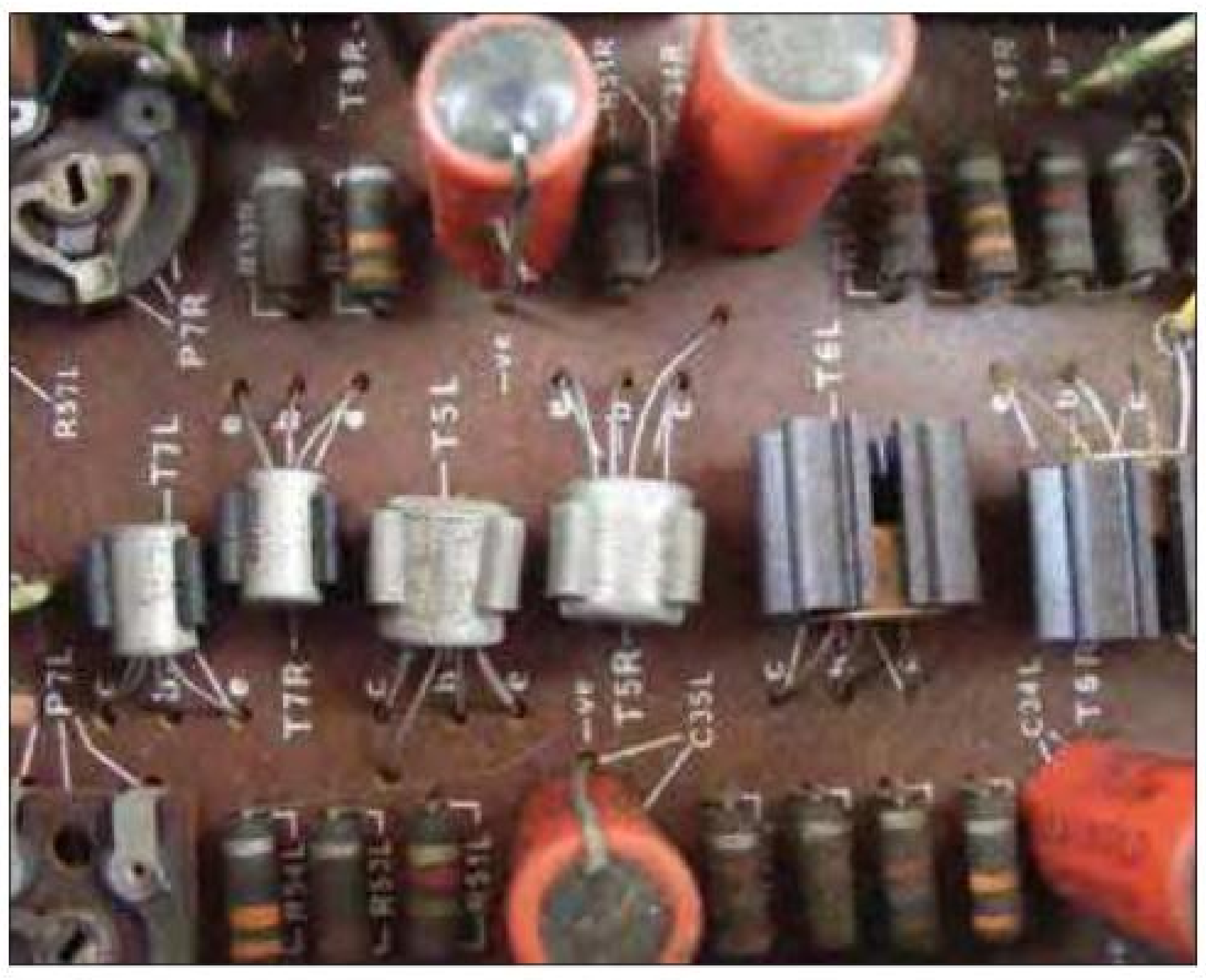


Fig.44. The two germanium driver transistors used in the Stereo 30, TR6 and TR7.

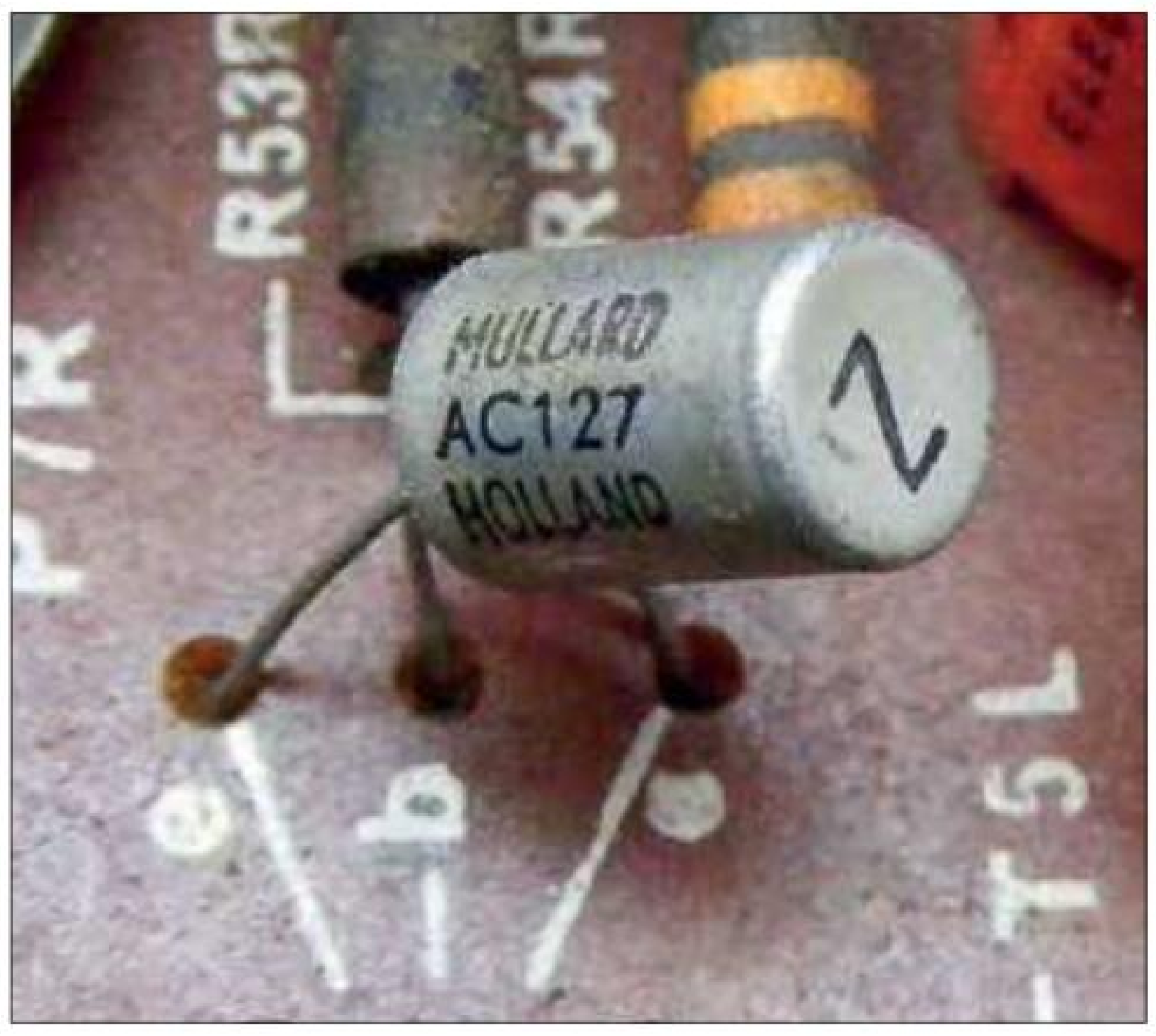


Fig.45. The rare AC127Z, the high voltage NPN TR7.

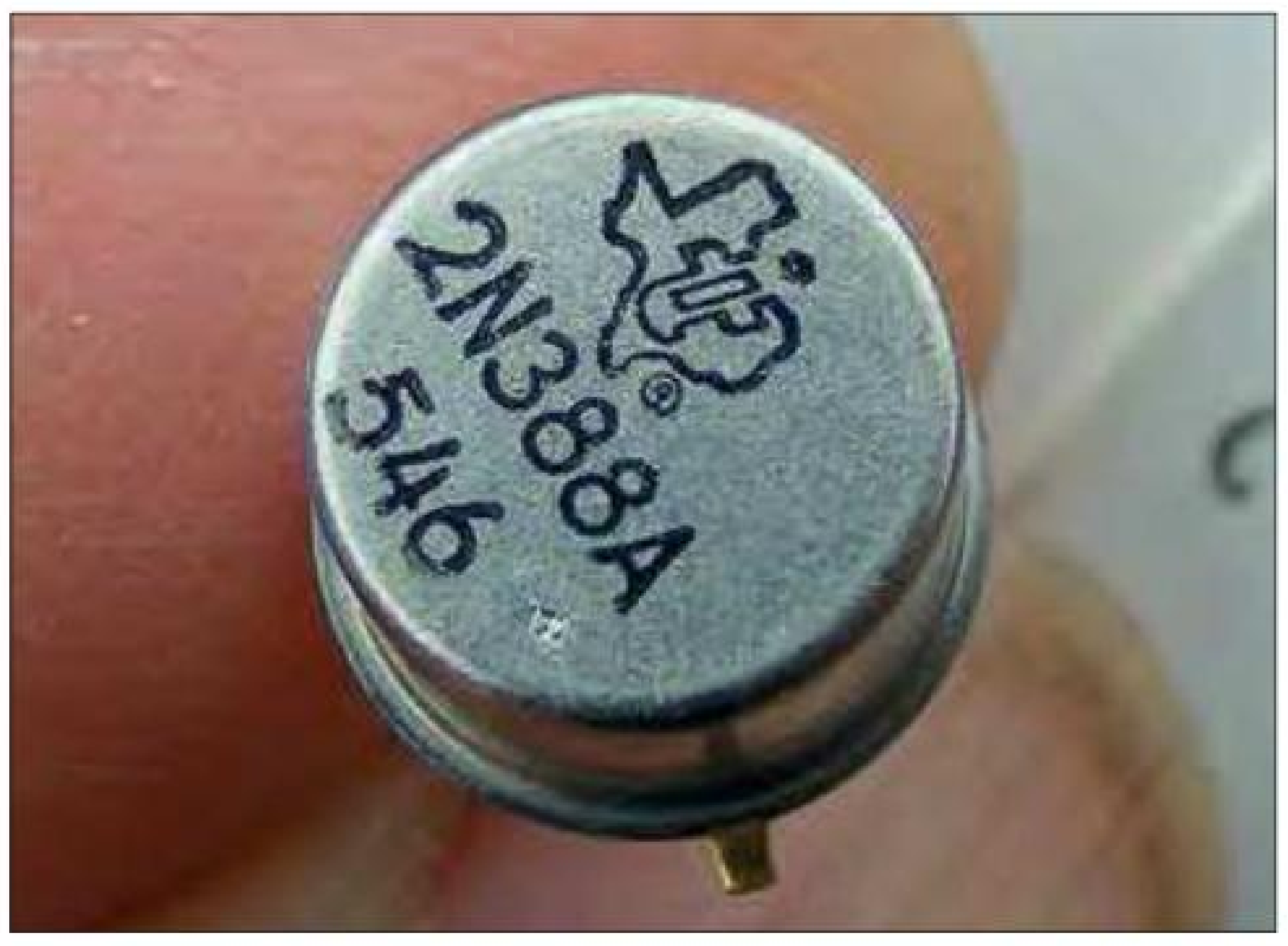


Fig.46. The mil-spec 2N388A NPN germanium transistor used by Toby Dinsdale. The late Bernard Patterson, a long-term *PE* subscriber, generously sent me a few.

for the possibility of high-power, high-frequency testing. For audio applications, a lower-rated device can be used.

The *TD Towers* book (Fig.50) is great for looking up data, but always check the equivalents suggested because they often have a lower voltage rating and therefore may not be suitable. In update 4, the BC153/4 are also incorrectly listed as NPN.

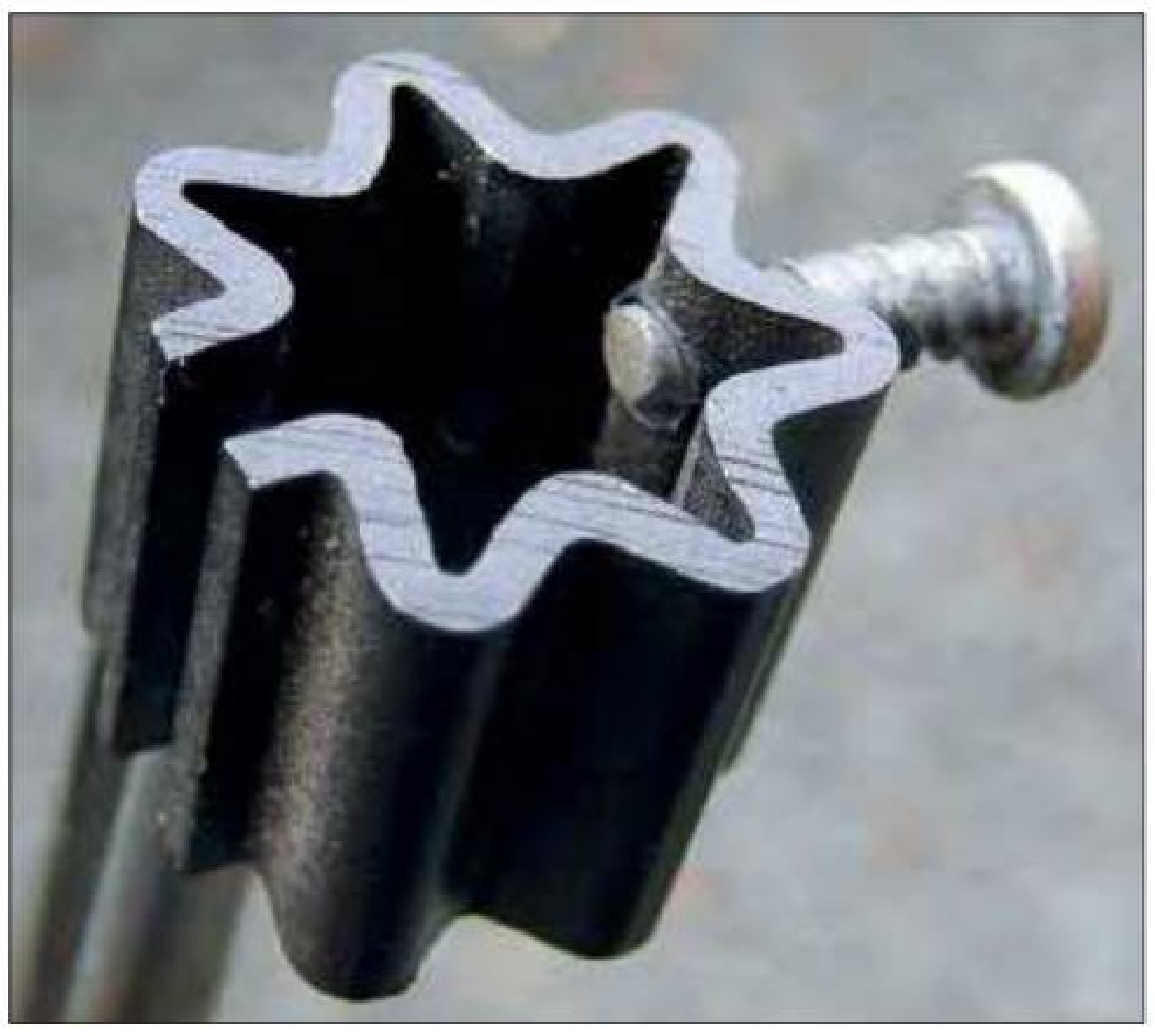


Fig.49. Tapped TO5 heatsink used for the GET538. People took great care with transistor mounting in the 1960s when they cost as much as a beer and sandwich.

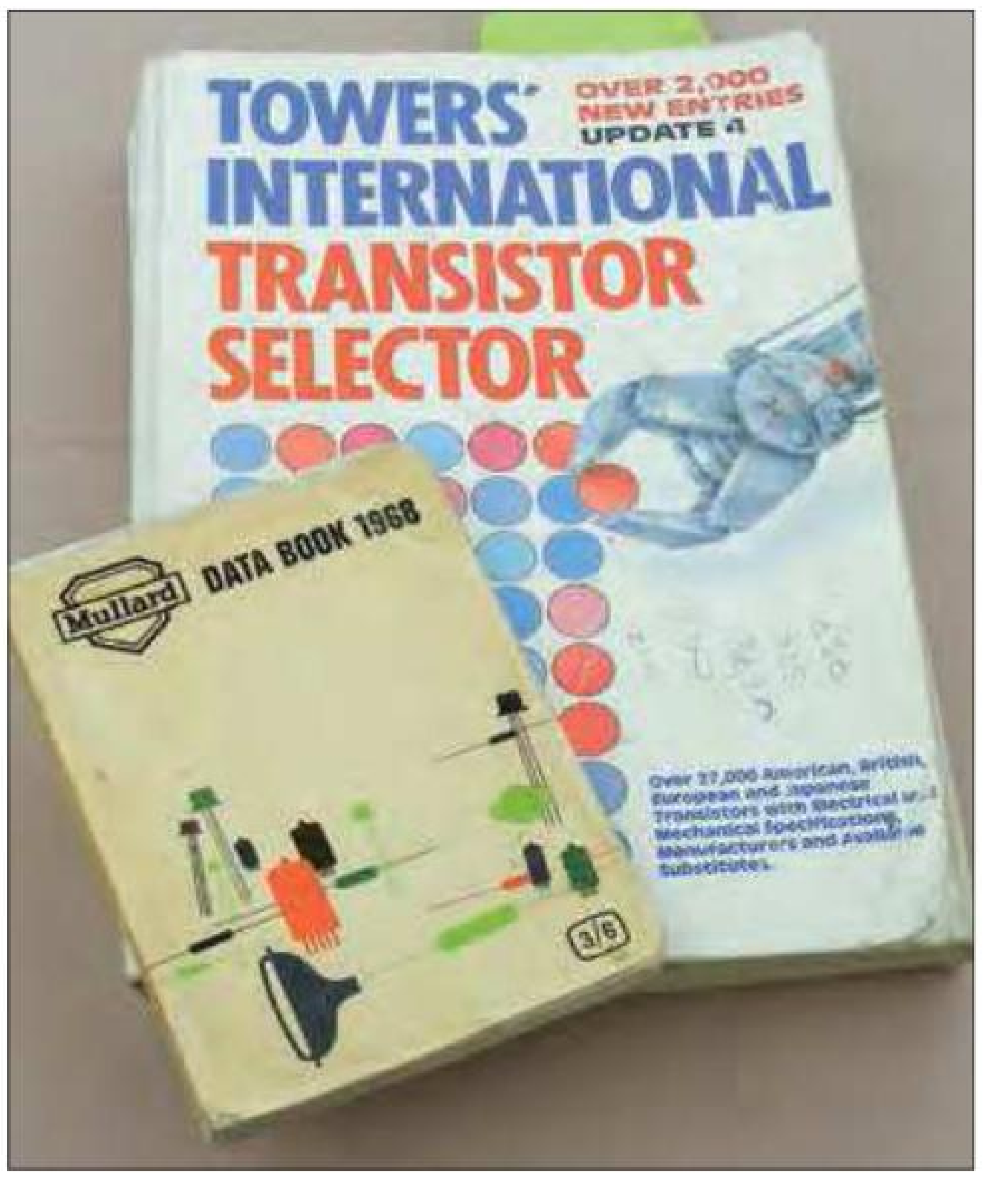

TOWERS'
OVER 2,000 NEW ENTRIES UPDATE 4
INTERNATIONAL
TRANSISTOR
SELECTOR
Mullard
DATA BOOK 1968

Fig.50. The *International Towers Transistor Selector*, a vital book for old electronic restorers and job-lot buyers of NOS transistors. The old Mullard pocketbooks are also useful for quick reference.

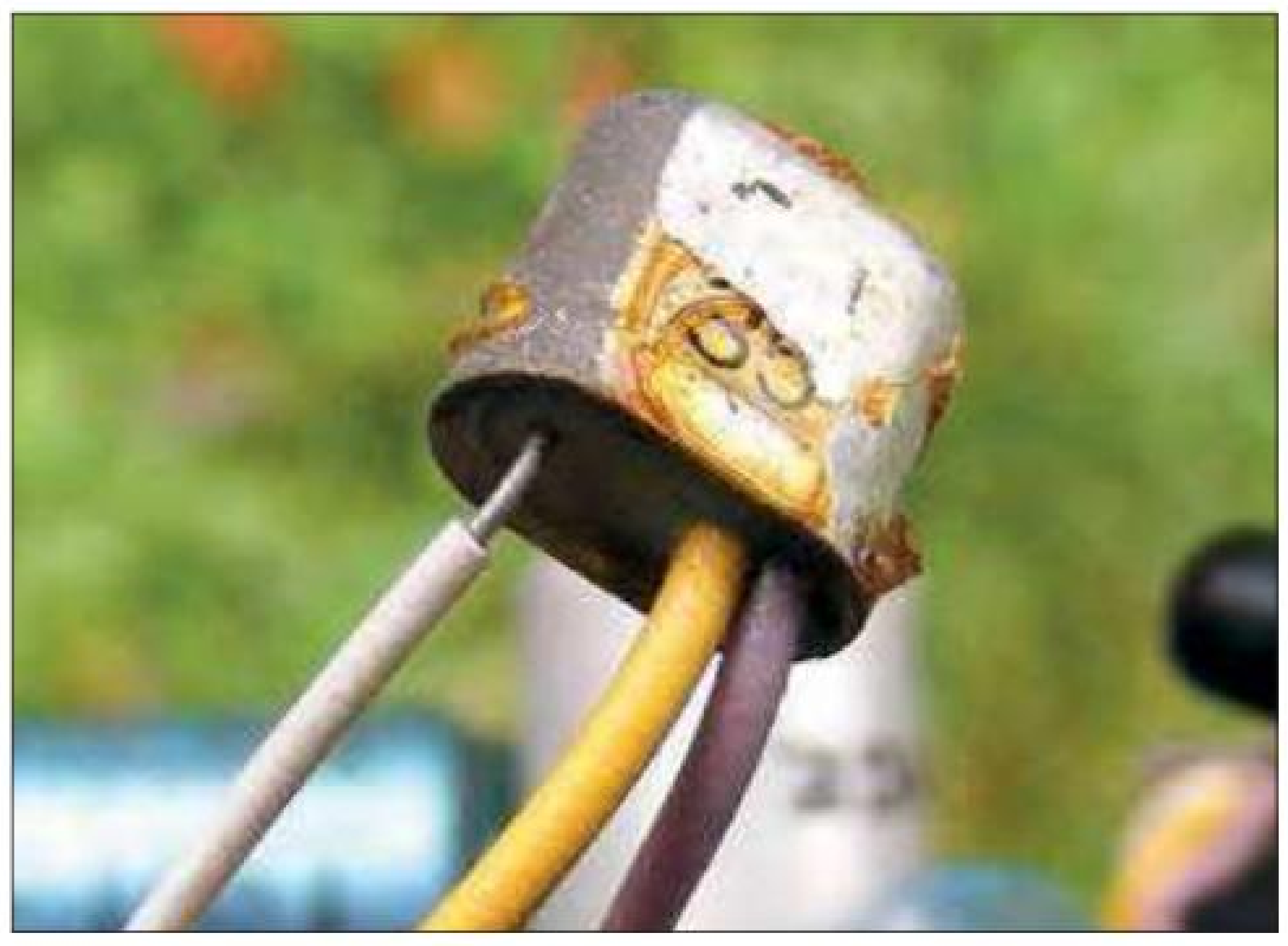


Fig.47. One of the first NPN transistors by Sylvania, who specialised in NPN devices. The 2N35 in its distinctive SO-4 can from an ancient Lin/Dinsdale amplifier in an old organ. Introduced in 1953, this transistor cost $4.45 in 1955! Jack Dinsdale used a similar device, the Syl 1750 which cost the considerable amount of 25 shillings (£1.25) from *Home Radio*, March 1962.

Selecting for voltage

I've used the NPN transistor ASY73 (30V V_{ce}) in a lower-voltage Dinsdale design. The same goes for the 2N1302s and 2N1304s. I use the Peak ZEN50 Zener diode analyser to test their V_{ce} breakdown voltage to see if they are suitable by joining the base and emitter. If the ZEN50 reports a V_{ce} breakdown voltage greater than 50V it can go in the Stereo 30. I'm not yet 100% sure about the long-term reliability of this technique, but it's shown in Fig.51 where V_Z is a substitute for V_{ce}. If there's no low-resistance path, say <1kΩ from the base to the emitter, or the base is left open, the voltage rating is reduced to the V_{ce} (open) rating. The Peak's current is limited to 2mA, so no damage to the transistor can occur.

Reducing the power rail voltage below 40V (recommended for 8Ω speakers) enables easier substitution of transistors.

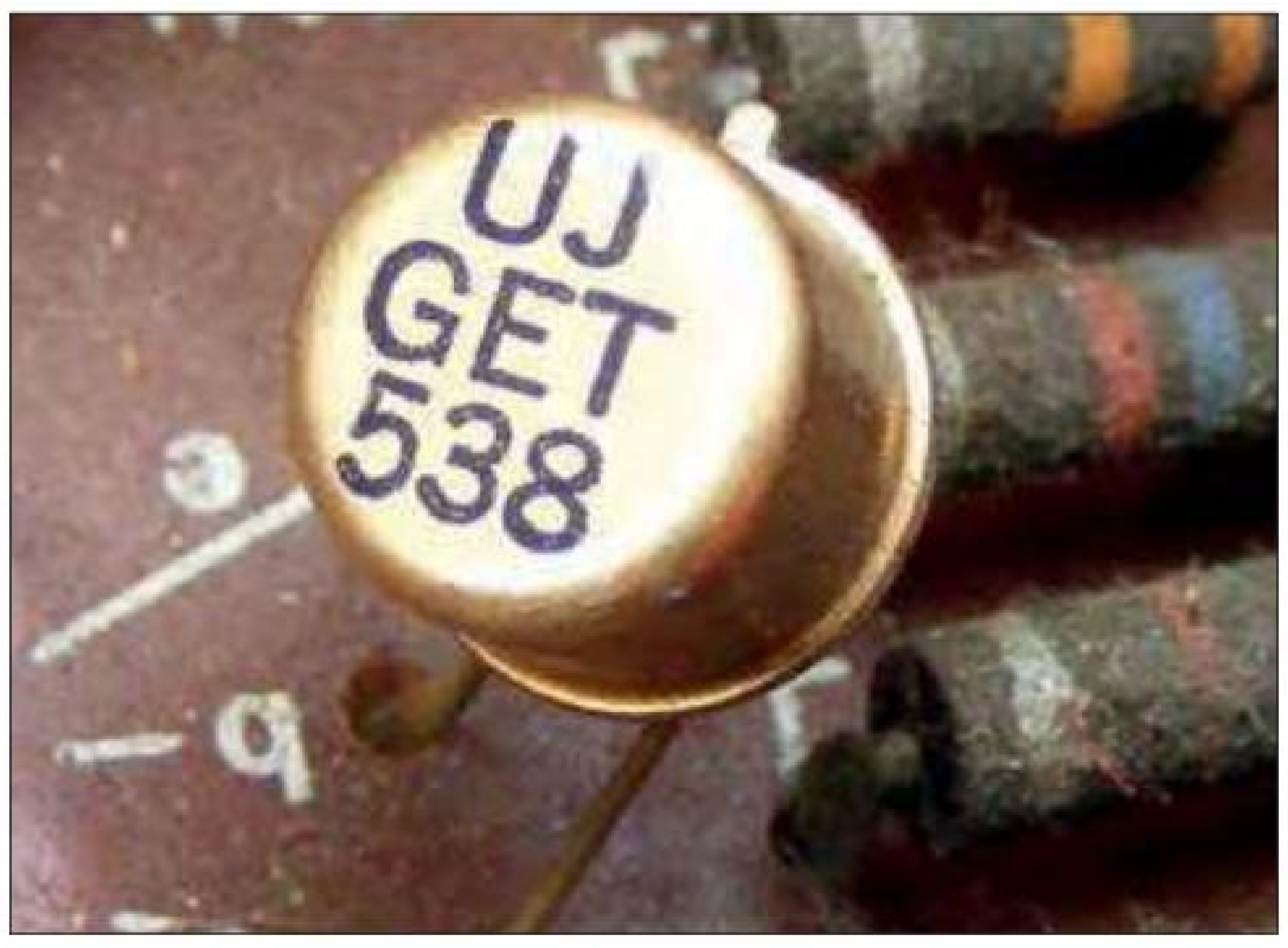


Fig.48. GET538 (TR6), a hard-to-get PNP driver transistor, replace with an ACY17.

This is achieved by setting the voltage selector to 250V (see *Practically Speaking*, February 2021). Transistors often have a higher actual breakdown voltage than the specification in practice. I've done this for ASY73s to replace the AC127Z and selected 2SA70s, which have a TO7 case, for the AF118.

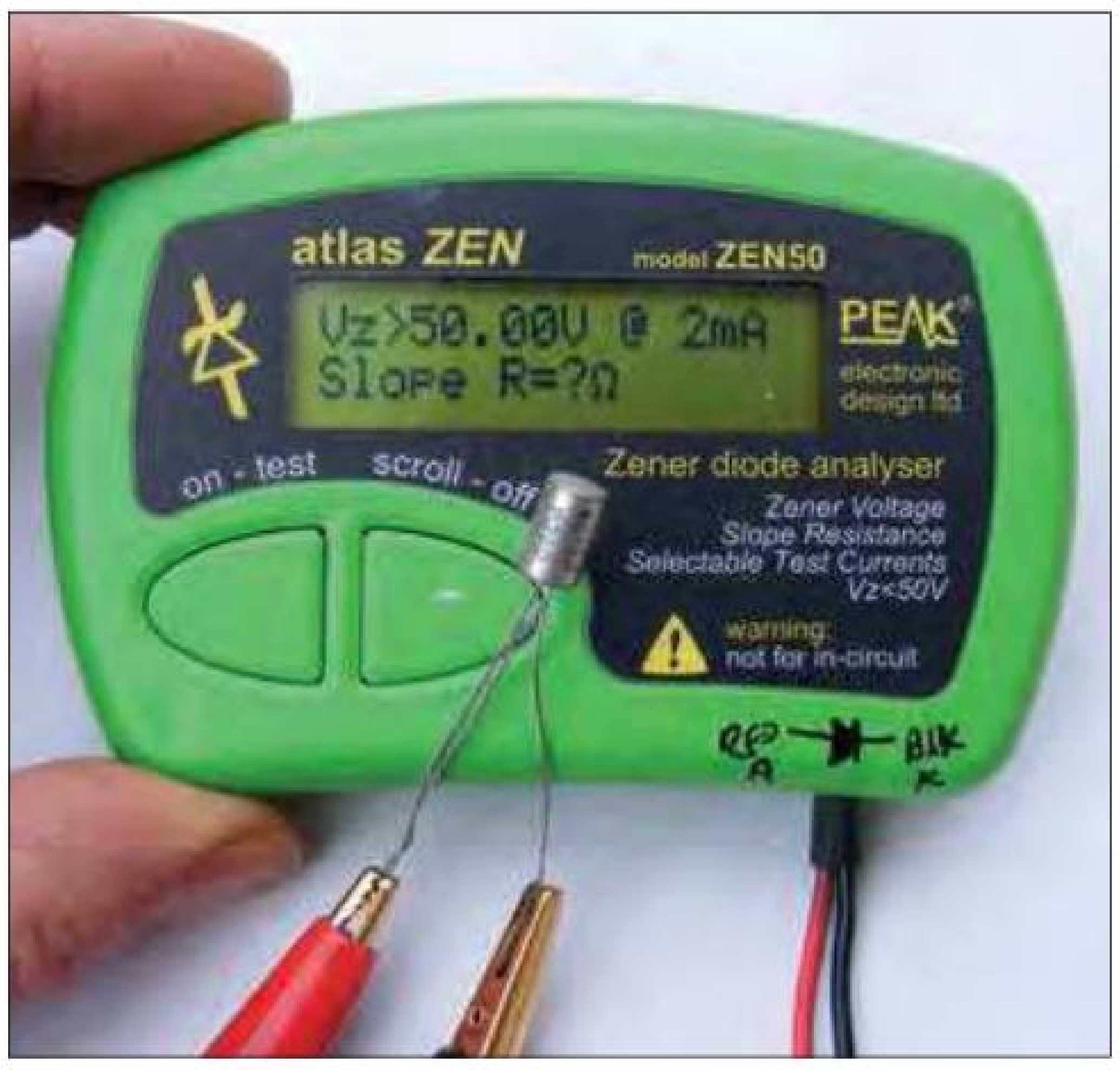

atlas ZEN
model ZEN50
Vz>50.00V @ 2mA
Slope R=?Ω
PEAK
electronic design ltd
on - test
scroll - off
Zener diode analyser
Zener Voltage
Slope Resistance
Selectable Test Currents
Vz<50V
warning:
not for in-circuit

Fig.51.Testing transistors for collector-emitter voltage breakdown (V_{ce}) with a Peak ZEN50 Zener diode tester. This AC188's V_{ce} is much higher than its stated minimum –32V rating, and could replace the GET538.

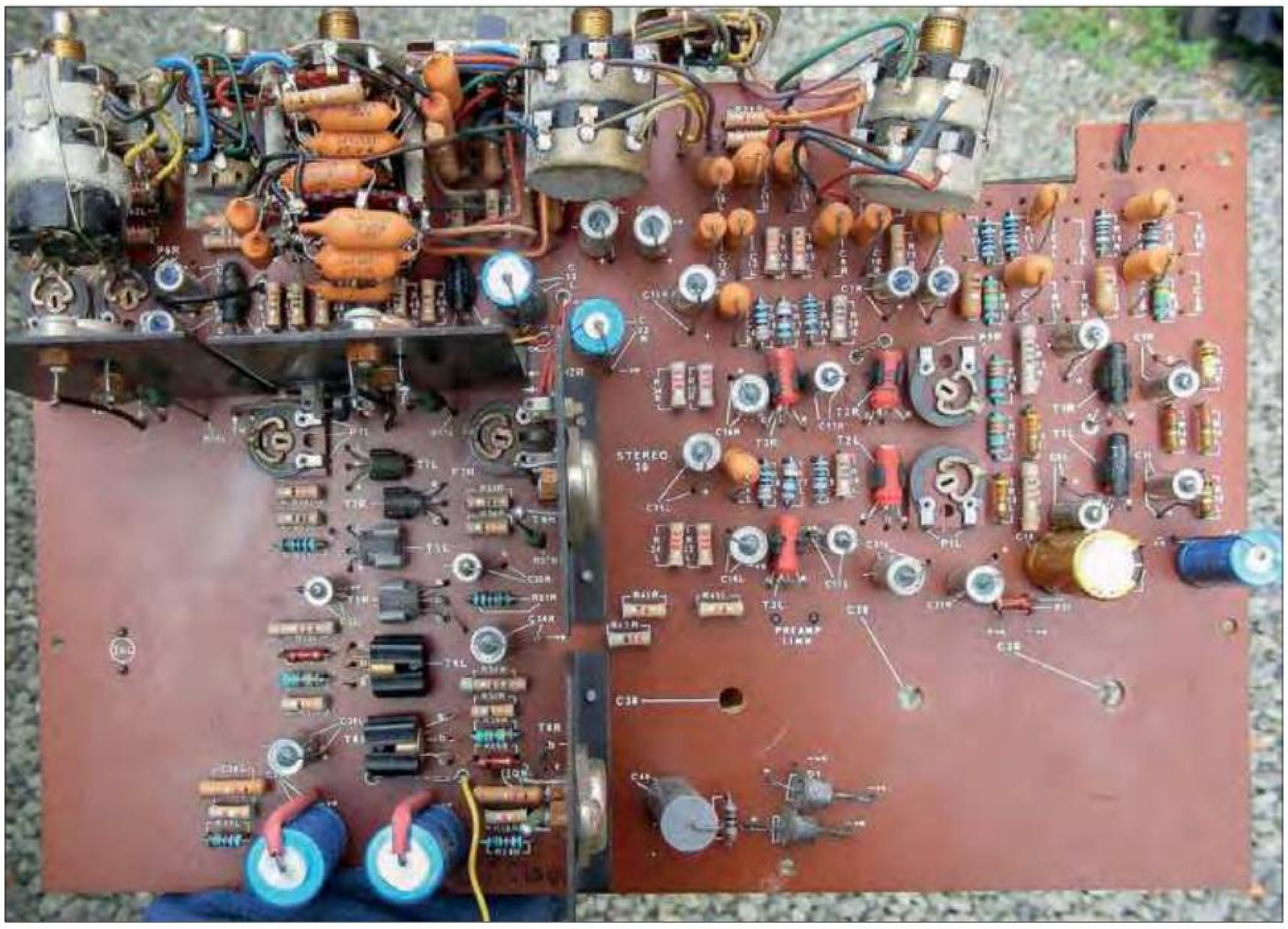


Fig.52. The DC bias point presets (P6) for the power amplifiers are hidden in the top left-hand corner.

Power transistors

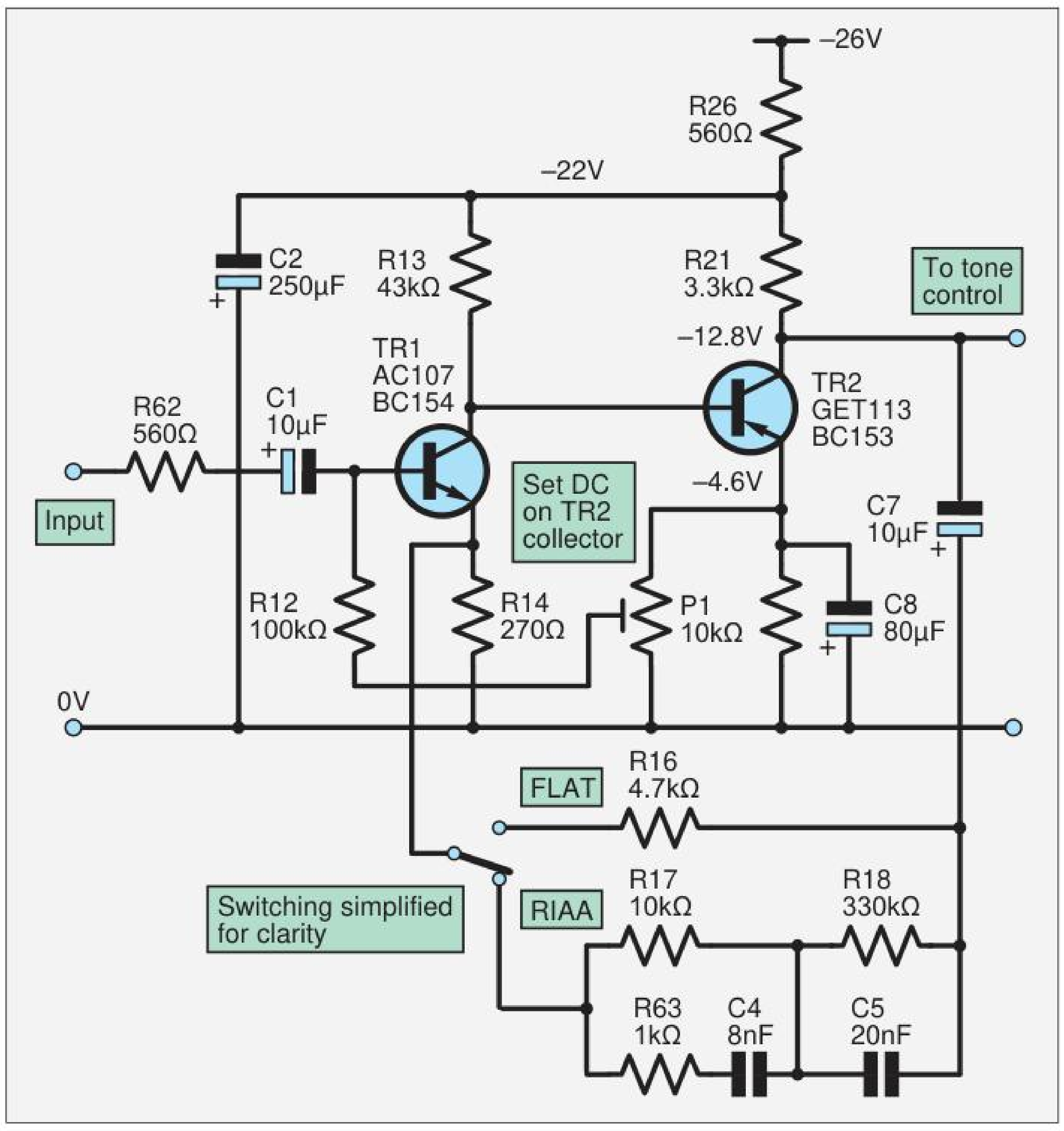
The Mullard AD140s, as fitted, seem to last quite well. They have a high V_{ce} voltage rating of 55V which possibly helps. The current rating is 3A. The driver and output transistors should all be germanium. It doesn't work pairing a silicon NPN driver with a germanium output transistor, since a nasty crossover asymmetry results. A quasi-comp output stage in silicon actually has edgier crossover distortion because of the sharper turn-on characteristic, unless a Baxandall diode is used, such as in some Naim amplifiers.

There are plenty of suitable output transistors, such as OC28, OC36, AD142, 2N2147, AU103, ASZ15, NKT401, AD149 and AL103, but I have a big stock of AD140s so that's what I use. The early Truvox amps used AD140s and later changed to AD149s. These were germanium's last fling as output transistors, before the all-conquering silicon 2N3055 took over.

OC25, OC29 and OC35 can be used in reduced voltage (35V) low-power Dinsdale designs. OC22, OC23, and OC24 have good high-frequency response for germanium (2MHz), but are only rated at 2A, so they are only suitable for a few watts. This is not sufficient for the Stereo 30.

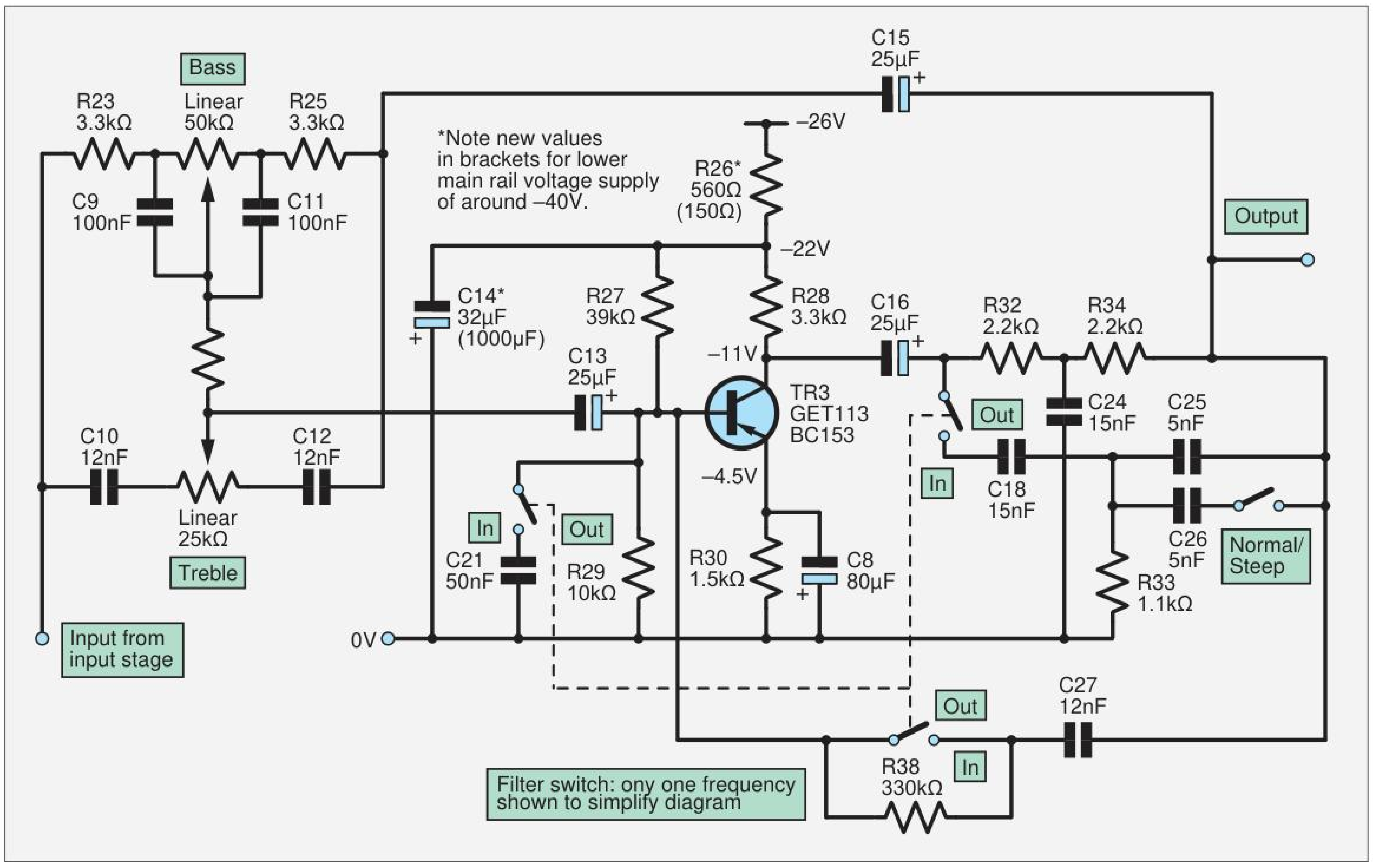
Power output

Testing with sinewaves for more than say 20 seconds at full power into a load can quickly overheat germanium transistors. It's prudent to gradually reduce the load resistance as testing progresses; say, from 100Ω to 8Ω. Germanium's maximum junction temperature is 90°C, half that of silicon devices. The Stereo 30 will give 10W RMS into 15Ω and 14W into 8Ω, but not for long. Using the reduced –38V HT voltage, it's 10W into 8Ω. Try doing this at 10kHz into a load resistor and you'll blow it up. In the past, loudspeakers had an inductive rise in impedance above 1kHz, which provided protection. Load resistors and modern speakers don't have this characteristic. This is the time to optimise the DC bias point at around 19V using P6 for symmetrical clipping (see Fig.52). Do this into an 8Ω load quickly at 1kHz. Remember, the heatsinks on most Hi-Fi amps are only big enough for short bursts of full power.



–26V
R26
560Ω
–22V
C2
250µF
R13
43kΩ
R21
3.3kΩ
To tone control
–12.8V
TR1
AC107
BC154
TR2
GET113
BC153
R62
560Ω
C1
10µF
Input
Set DC on TR2 collector
–4.6V
C7
10µF
R12
100kΩ
R14
270Ω
P1
10kΩ
C8
80µF
0V
FLAT
R16
4.7kΩ
Switching simplified for clarity
RIAA
R17
10kΩ
R18
330kΩ
R63
1kΩ
C4
8nF
C5
20nF

Fig.53. a) (above) The input stage set for the preamplifier RIAA input. Two transistors do not give enough open-loop gain so the distortion is high. The AC107 was considered one of the lowest-noise transistors at the time. b) (below) The tone control stage uses a single transistor. Distortion is 1% with bass boost, but sounds interesting.



Bass
R23
3.3kΩ
Linear
50kΩ
R25
3.3kΩ
C9
100nF
C11
100nF
*Note new values in brackets for lower main rail voltage supply of around –40V.
C15
25µF
–26V
R26*
560Ω
(150Ω)
Output
–22V
C14*
32µF
(1000µF)
R27
39kΩ
R28
3.3kΩ
C16
25µF
R32
2.2kΩ
R34
2.2kΩ
C13
25µF
–11V
TR3
GET113
BC153
Out
C24
15nF
C25
5nF
C10
12nF
C12
12nF
In
C18
15nF
–4.5V
Linear
25kΩ
Treble
In
Out
C21
50nF
R29
10kΩ
R30
1.5kΩ
C8
80µF
C26
5nF
Normal/
Steep
R33
1.1kΩ
Input from input stage
0V
Out
C27
12nF
R38
330kΩ
In
Filter switch: ony one frequency shown to simplify diagram

The preamplifier

The pre-amp channel only uses three transistors, an exercise in minimal circuit design, reflecting their cost at the time. This is shown in Fig.53. There are two parts, the input + RIAA stage and the Baxandall tone control/filter. Once the resistors and capacitors have been checked, it rarely has faults. A tweak of DC bias pot P1 (Fig.32) is often needed, which should give a collector voltage of around 12V on TR2. The AB/Blore-Edwards pots used are usually okay if not corroded. Locked spindles can usually be freed by using power-steering fluid, basically a light mineral oil with a detergent in it. WD40 and 151 maintenance spray will also work. The distortion and noise level are fairly high. The increase in distortion that occurs when the bass control is advanced is subjectively quite nice. The filter is useful if scratchy records from the charity shop are played.

Improvements

There are a few reversible improvements one can make; here are some ideas to play with.

Gain structure

The preamplifier line inputs were designed for low-level 100mV$_{rms}$ outputs from FM tuners. For some of today's digital sources, such as CD players with 775mV$_{rms}$ level there is too much gain. Lowering R16 to 1kΩ can reduce this by almost a factor of four, making a higher-level line-input. Even this is still too much for a CD player and extra attenuation is needed with a potential divider on the input. The same mod works with tape head and microphone inputs, facilities which are not required today. On the eBay amplifier I rewired the switch so the line inputs went into the tone control input. However, this mod is not easily reversible and requires that C13 (polarised capacitor) is turned round. It did sound much better; even though the high gain combined with attenuation in the preamplifier breaks one of the main rules of high-quality audio.

Coupling capacitors

Making the output electrolytics (C37, as shown in Fig.54) bigger is useful; 1000µF is only just big enough for 15Ω speakers, so I

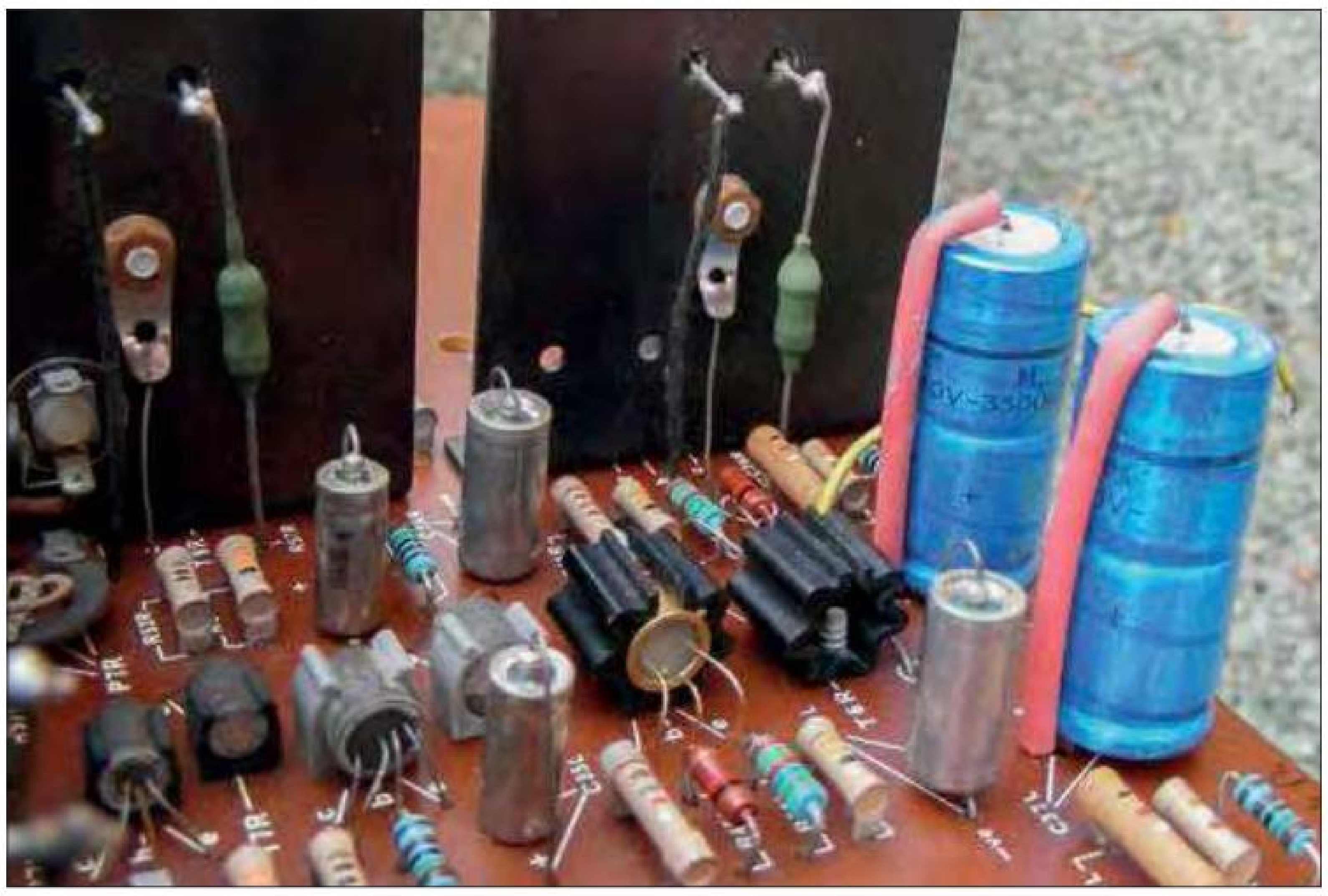


Fig.54. The original output capacitors were insufficient in capacitance and voltage. I installed these big axial Philips/BC electronics/Vishay electrolytics. The top of these caps is a good place to do the output half-rail voltage check.

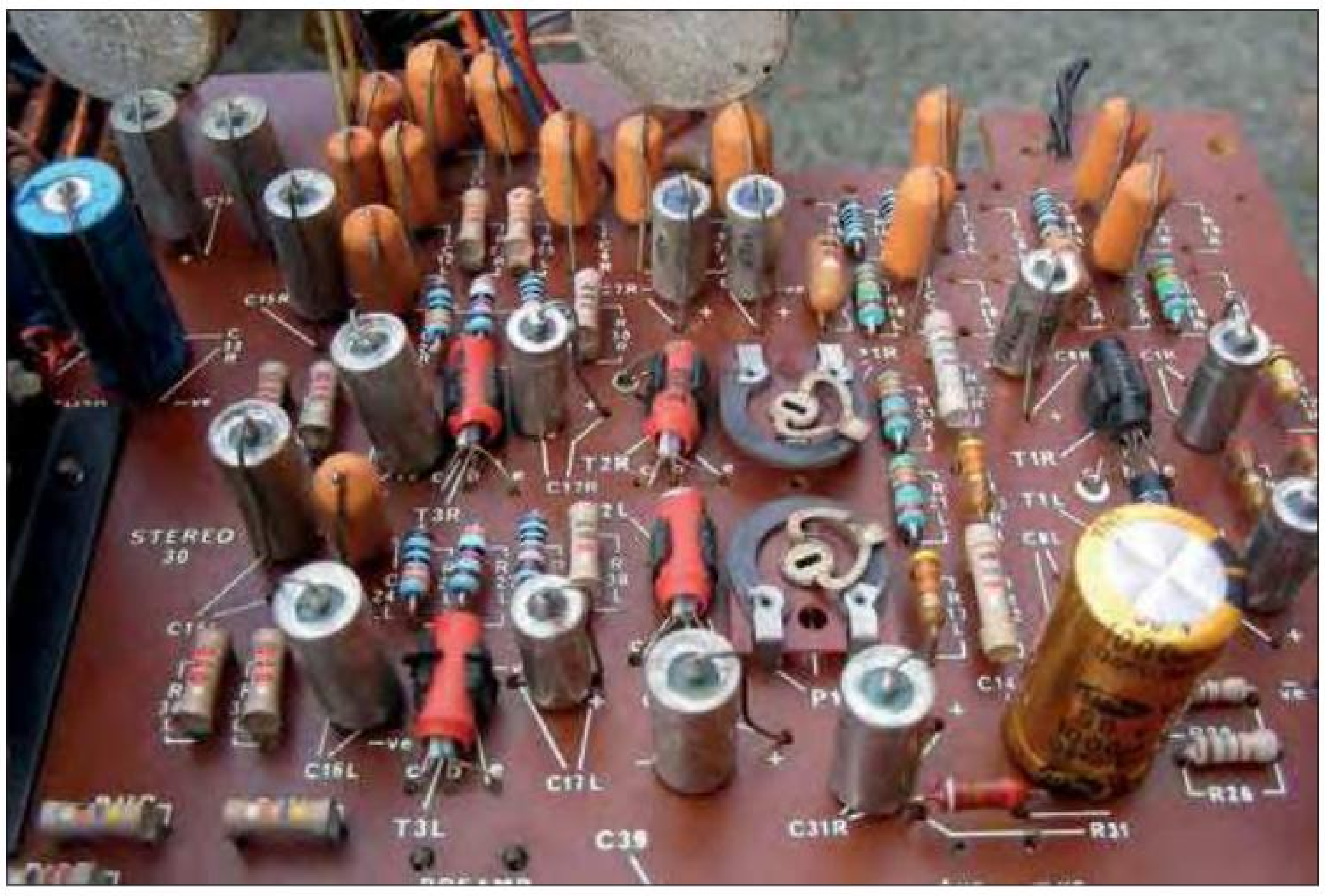


Fig.55. Old axial solid-tantalum capacitors make a good replacement for old axial electrolytic types; they seem to last forever. These ones were in an RAF store for 50 years, all perfect. Note the much larger, gold-coloured C14 decoupling capacitor.

upgraded to 3300μF 40V. I worry about the original rating of 25V with a 42V rail should the amplifier fail hard-on. It could take the speakers out if the capacitor breaks down. Modern electrolytics are much smaller and better, so this is an improvement recommended for all capacitor-coupled amplifiers.

Make C1 bigger: the circuit diagram in Fig.53 specifies 10μF, but the 1964 amplifier originally had just 1μF fitted. The rise in impedance at low frequencies increased the noise on the turntable magnetic pick-up input. I further raised the value of C1, and put in a 100μF 6V metal-cased solid-tantalum capacitor of 1969 vintage. These old types of capacitor do not deteriorate with time, so are an ideal NOS 'antique' replacement, as shown in Fig.55.

Silicon sacrilege

Leak did one improvement themselves a few years later. They replaced all the germanium small-signal transistors with what were then the only low-cost PNP silicon transistors, a BC154 for TR1 and BC153s for TR2, 3 and 4. They had unusual TO106 epoxy cases (Fig.56). This reduced the noise level. TR5 could also be replaced with a silicon transistor, such as a BC327, with no real difference in sound quality. It's very tempting to try some distortion-reducing tricks developed in the silicon era, such as the Baxandall diode, going back and applying them to germanium. A simple mod to the tone control would be a bootstrapped collector load and emitter follower. (See G Hibbert, *Circuit Ideas*, p,89, *Wireless World*, April 1980).

Fig.56. Later models of the Stereo 30 dispensed with the small-signal germanium transistors and used these early PNP silicon BC153 and BC154 transistors.

Constant-current sources

Another 'high-tech' addition which I've yet to fully analyse would be to replace the collector load resistors R21 and R28 with 2.7mA current-regulator diodes (CRD) reducing distortion by increasing the open-loop gain. Another 2.7mA CRD in the collector load (R50) of TR5 may reduce the dreaded crossover distortion. It's essential to get these CRDs the right way otherwise they are almost a short circuit and you will blow your transistors up.

New sockets

On the eBay amplifier the power cord had been cut off, so I put in an IEC socket in place of the mains outlet sockets, another facility no one uses today. The new socket can be fitted in the exiating rectangular hole by just enlarging the screw holes to 4mm. This mod is shown in Fig.57. New phono connectors were also fitted with simplified switching, shown in Fig.58.

Odd distortion

I noticed a DC bias shift with signal level causing lower cycle clipping after a loud burst. This was a strange form of 'delayed distortion' that took a lot of tracking down. The cause of this was power supply droop on the preamplifier. There is no regulation, only RC decoupling, so when a loud transient is reproduced the preamplifier DC bias can drift about as well. This effect was reduced by altering the decoupling components, reducing R26 to 150Ω and increasing C14 to 1000μF (Fig.53b, Fig.55). The lower resistance was necessary to maintain the voltage to accommodate the reduced rail voltage of 38V. Of course, a regulator could be installed.

Was it worth it?

Economically, it doesn't make sense. For several days work the value has increased from £26 to £60. However, I love it for its physical embodiment of early transistor technology and its build quality. It doesn't sound as good as a complementary silicon amplifier, having its own unique slightly 'woolly' sound, but it's good enough for a second Hi-Fi system used at low volume for the home office, especially a 1960s-themed office with an Olivetti typewriter! I'll be using it in lectures on amplifier design, so it will earn its keep.

Next time we'll have a look at restoring older silicon designs, such as the million-selling NAD amplifier series.

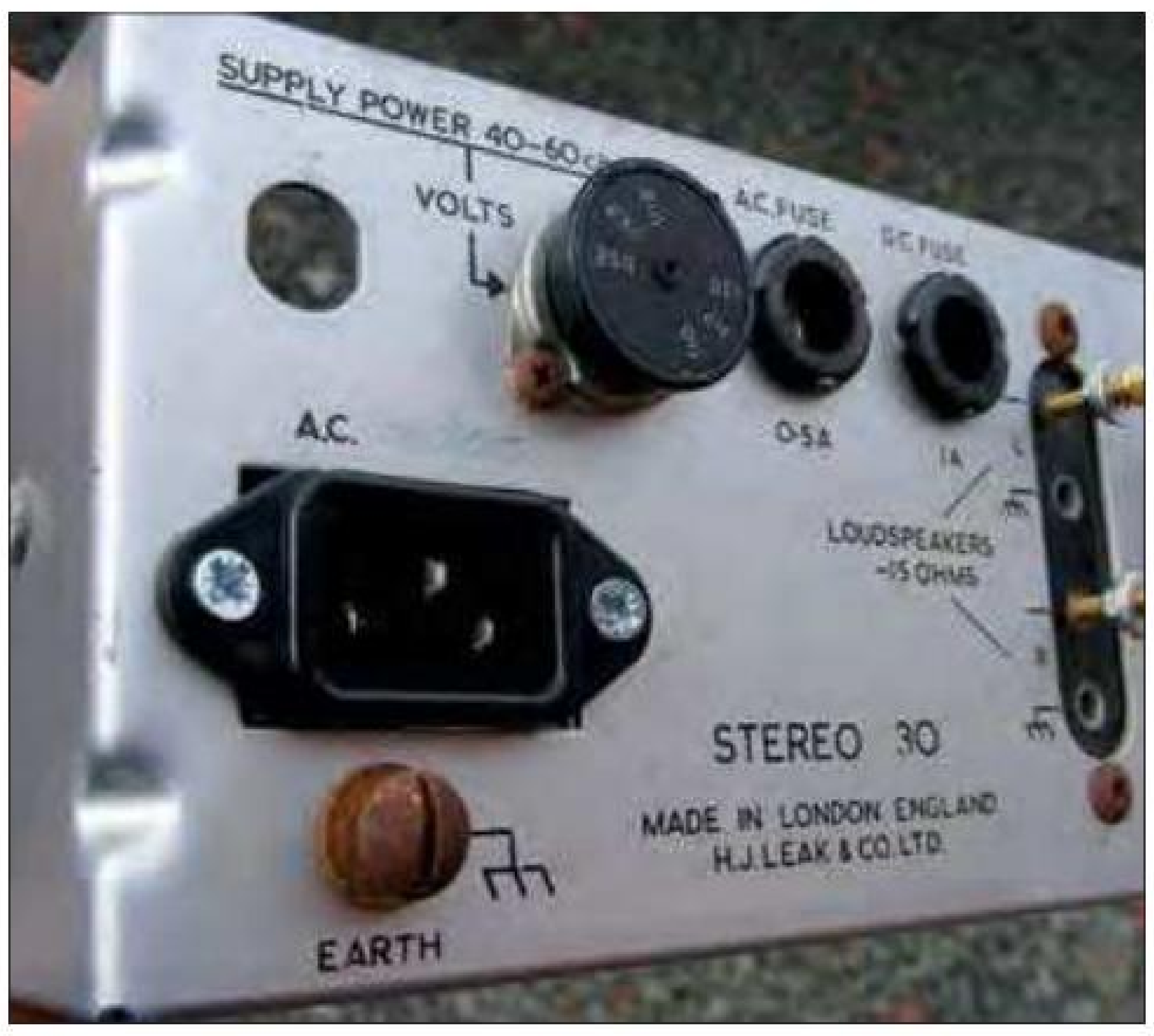


Fig.57. A lot of dumped equipment will have had their power cords cut off by overzealous technicians, especially in the public and educational sectors. It's a good excuse to then add a proper IEC mains connector.

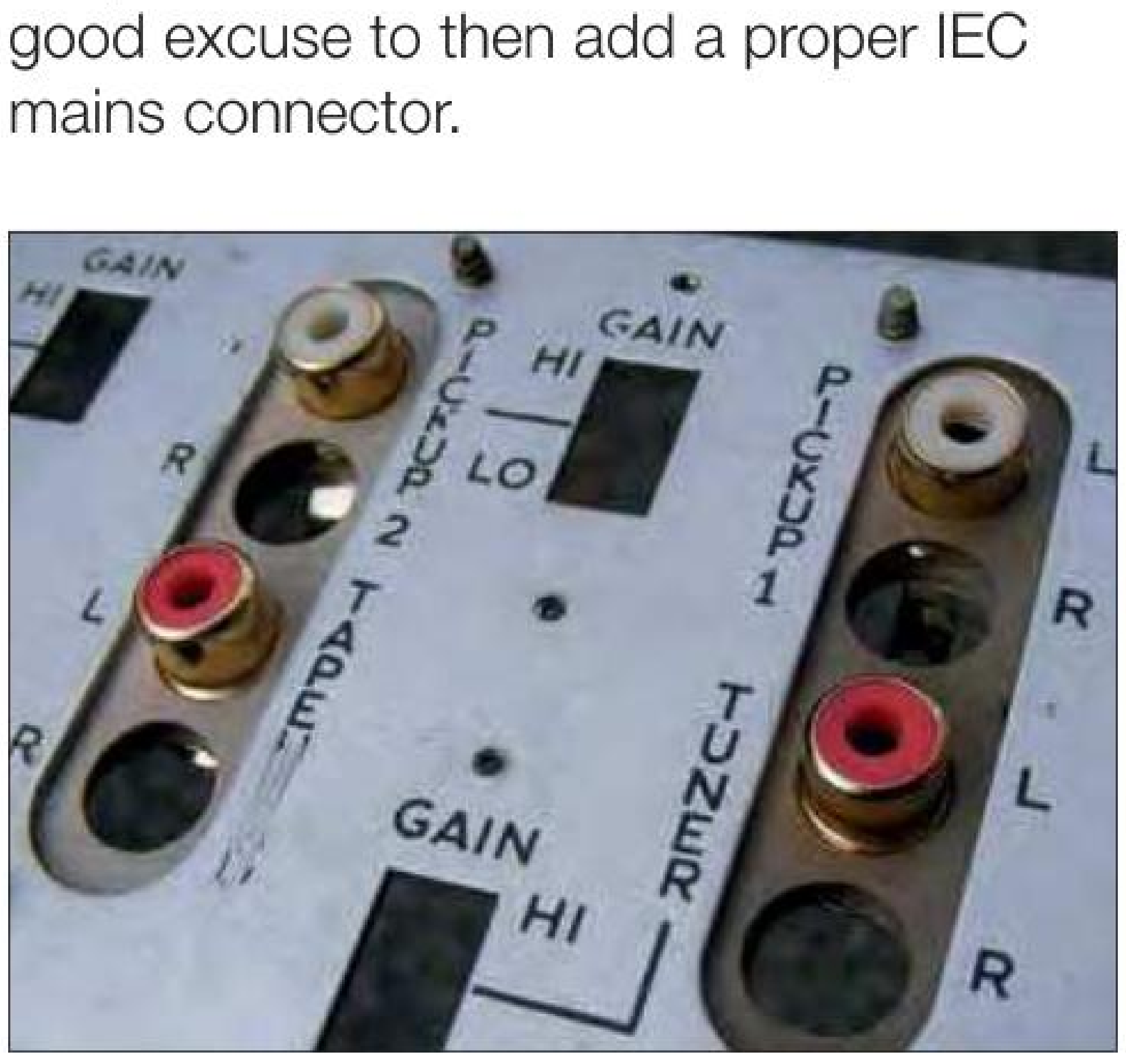


Fig.58. New phono connectors were required on the eBay amp, but were a pig to fit. I had to use the insulating plates from the old phonos.

AOShop

The home for specialist audio, analogue and historic components – provided by Jake Rothman, *PE's Audio Out* columnist. The AOShop is your best bet for classic analogue 'NOS' (new old stock) components, including all parts for *Audio Out* projects and designs.

Ge semiconductors

Small-signal PNP transistors	
AC125, AC126 (CV7003), NKT214F, OC57, OC59	£1.00
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High-voltage PNP transistors	
OC77, CV7001, 2N525	£1.50
TO3 PNP power transistors	
OC22, CV7054 (OC23), OC25, OC35, OC36, AD143, AD149, AD161, AD162	£2.00
AD140	£3.50
AD149 matched pair	£5.00
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NPN transistors	
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Low-noise silicon transistors	
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2SC2204, 2SD655	£0.50
ZTX651	£0.30
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BF199	£0.50
BF245	£0.60
Audio power MOSFETs	
Exicon 10N20, 10P20	£6.50
Hitachi 2SJ99, 2SK343	£3.50
Hitachi 2SJ 50, 2SK135	£7.00
Hitachi 2SJ56, 2SK176	£8.50
JFETs	
BFW11, BFW10, TIS73L, J177, J113, U1994, U1898	£1.00
MOSFETs	
ZVP2106A	£0.30
Dual-gate 3SK45, BFS28	£1.50
Metal-cased transistors	
BC143	£0.35
2N1711	£0.50
BCY71	£0.30
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Amplifiers	
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μA709 metal-cased op amp	£2.00
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3.5-inch 25Ω	£3.50
5x3-inch elliptical 50Ω or 80Ω	£3.50
1.65x2.75-inch 8Ω	£1.50

Can't see what you want? Just ask – we have a huge stock of inexpensive high-quality parts!

Capacitors

Note '10/63' denotes '10μF 63V'.

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5.6/63, 8.2/63, 10/63	£2.00
Mullard 'Mustard' C296 0.22/400	£2.00
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Axial 2.2/63 1%, 4.7/160, 6.8/63	£1.00
Radial	
6.8/160V, 10/63	£2.00
Reclaimed 22/63	£2.00
Polystyrene	
Philips 1% 4.7nF/160, 22nF/63, 110nF/63	£1.00
RIFA 1% 100nF/100	£2.00
Suflex 2.5% 10nF/63 (rad. or ax.)	£0.50
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10/25, 22/25, 100/10	£0.50
150/40, 470/40,1000/40	£1.00
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22/50, 47/35, 68/25, 100/20, 120/10, 150/16, 220/10, 330/6	£2.00
22/35, 33/35, 47/20, 68/15, 100/10, 150/6	£1.25
4.7/50, 6.8/35, 10/25, 10/35, 22/15	£1.00
Moulded-case tantalum	
Kemet axial 6.8/10	£0.30
Kemet radial 33/10	£0.40
STC radial 100/20	£1.50
Tantalum bead	
22/50	£1.00
470/3	£2.00
680/6.3	£3.00
Wet tantalum	
220/25 axial	£3.20
Castanet button 140/30, 470/3	£3.20
Hughes 540/10	£3.20
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Hermetic bipolar tantalum 16/35	£3.20
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47/16	£1.00
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10/16	£0.30
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4.7nF/500 5%	£1.00
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Vigortronix 600Ω VTX-101-3001	£10
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Thermistor RA53	£4.00
Thermistor CZ1	£1.50
Holco H2 2.2MΩ 1W	£1.00
Welwyn 1GΩ 2W	£1.00
Allen Bradley 1.2kΩ 2W C-comp	£1.00

Lots of big valve resistors available.

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Plessey moulded-track	
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50kΩ A/log	£3.00
Mil 250kΩ lin dual	£5.00
Alpha	
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220kΩ A/log	£0.80
10kΩ lin centre-detent dual-gang	£1.50
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Blore Edwards AB 45 dual 5kΩ A/log with switch	£3.50
Alps RK9 dual-gang 5kΩ RD law	£4.00
BI P260 500kΩ log conductive plastic 1 million cycles	£3.00
Colvern wire-wound 100kΩ or 50kΩ dual-gang 3W	£8.00
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MH1 4-pole 3-way	£3.00
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PIC n' Mix

Mike Hibbett's column for PIC project enlightenment and related topics

Part 6: PIC18F Development Board

We continue this month with building programs to run on our PIC18F development board. In May's article we built our first test application which only turned on an LED, just to prove things were basically operational. This month, and over the next few articles, we test the capabilities of the platform by building a more functional application, with a very practical use. More on that later.

In the weeks that followed our previous article the revision 2 PCB was manufactured, and two complete sets of the components from the recommended sources ordered. You can see the kit of parts in Fig.1 – some assembly required! While you are free to obtain components from any source, parts can vary in performance or physical dimensions, so it is important to set a baseline source of parts and validate everything fits and works.

Regarding components, we do strongly recommend fitting sockets and header pins. While not essential, it significantly reduces the effort required to replace a sensitive component should it become damaged – and we have more than once 'blown up' a circuit through accidental shorts, over-voltage or wiring errors. The LCD, USB connector, SD Media connector and Wi-Fi interface are all options, and they can be left for later, or at least ordered cheaply from China with long delivery lead times. It's best to keep these optional boards connected to the main development board with headers (with the exception of the USB connector, that could be directly soldered) to give flexibility for the re-use of those pins for other applications. Using sockets also means that if you build a circuit board for a specific project, you can temporarily pop the ICs out and re-use them.

PIC n' Mix PIC18F Development Board

The PCB for the *PIC18F Development Board* is available from the *PE PCB Service* – see the July 2021 section.

www.electronpublishing.com/product-category/pe-pcb-service/

Board assembly

The PCB is available from the *PE PCB Service* (code PNM-JUL21). Assembly follows the usual through-hole component order. There are no complex or unusual components to fit, nor special skills or tools required. When ordering parts, it would be a good time to check whether you should purchase some useful accessory tools – de-soldering braid, isopropyl alcohol and a toothbrush (for cleaning the board after soldering) are useful. Remember, the main component distributors charge shipping fees for 'low-value' orders, so now is a good time to buy additional items.

The sequence of component assembly is not critical, but we would suggest starting with the IC sockets, fixed-value resistors, diodes and capacitors. Please remember that two of the capacitors, the 10µF tantalums (C1 and C4), are polarised and must be fitted with the correct orientation, as shown in Fig.2. Fit this incorrectly and your board may work for a while, then exhibit odd failures!

Proceed with fitting the LED, transistors and LM317 regulator. When soldering the LM317 regulator, take care where you bend the leads. If you plan to bolt the regulator to the PCB, do that *before* soldering the leads. If you don't, you will place stress on the packaging which could result in an early failure of the device. Bolting the regulator down is not a necessity, but it does provide mechanical stability and a slight improvement in heat dissipation. In most uses, however, we would not expect the regulator to run hot.

Make sure you trim back excess wires after soldering, to avoid electrical shorts, or scratches appearing on your workbench. Follow on by fitting the variable resistors, power socket, header sockets and header pins.

Now fit the small 32kHz crystal – leave that component to the end because it is delicate with thin wires that will snap off if bent too much. Complete the board by fitting the three ICs into their sockets, affixing four rubber adhesive feet to the bottom, and last but not least, admiring your handiwork!

At this point you should check for shorts across the voltage rails and then run the simple application presented in

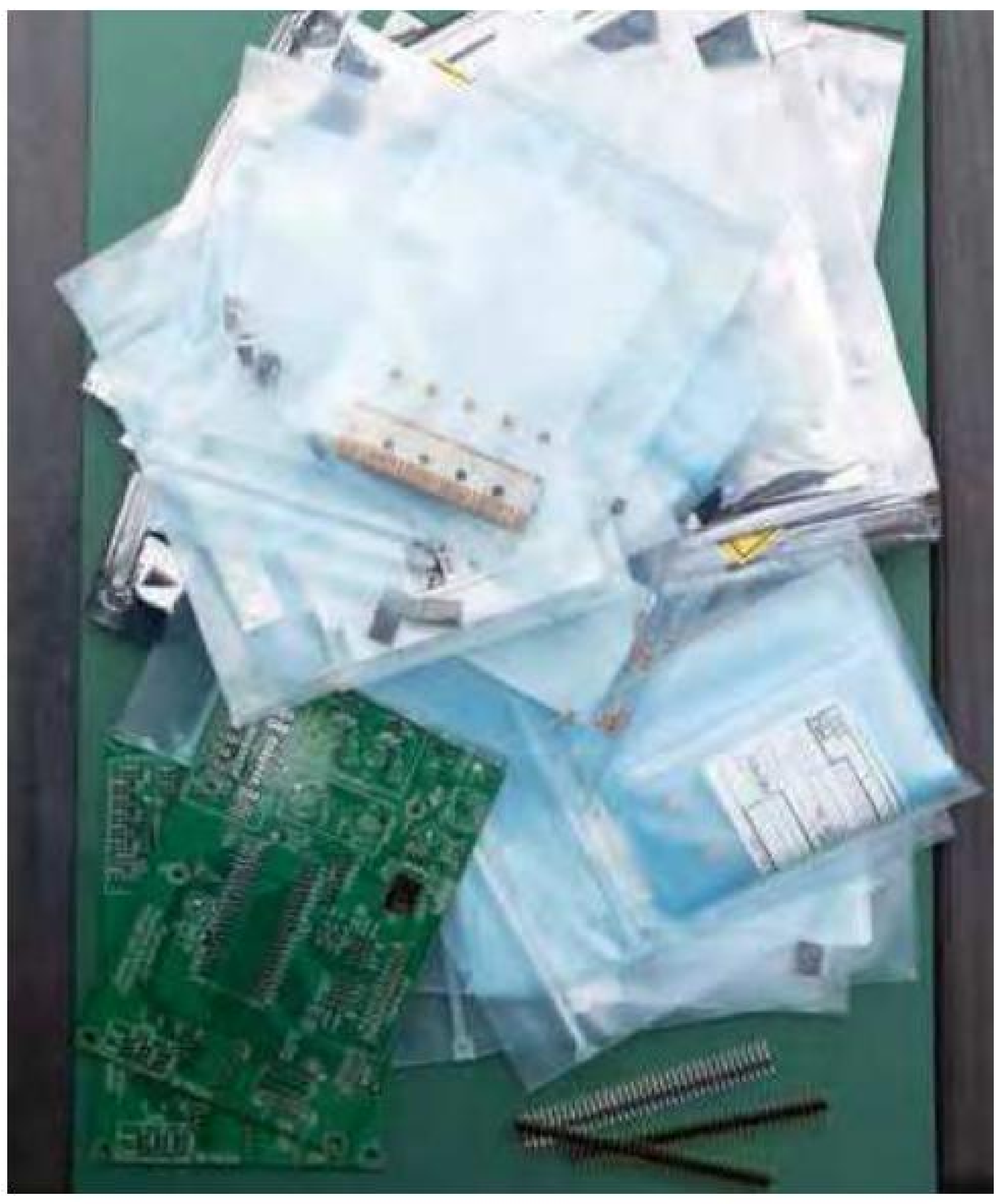


Fig.1. The *Development Board* parts.

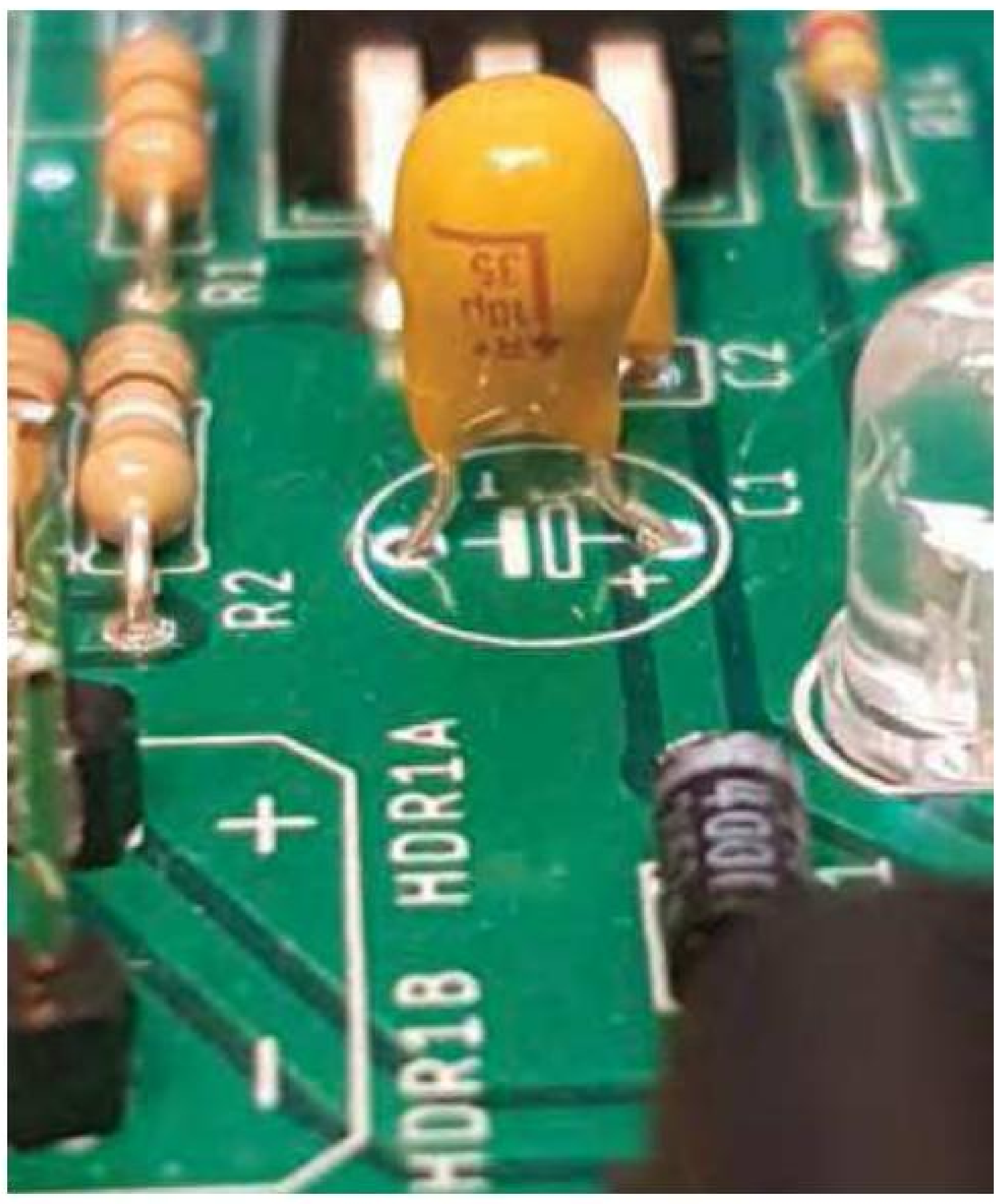


Fig.2. Tantalum capacitor orientation.

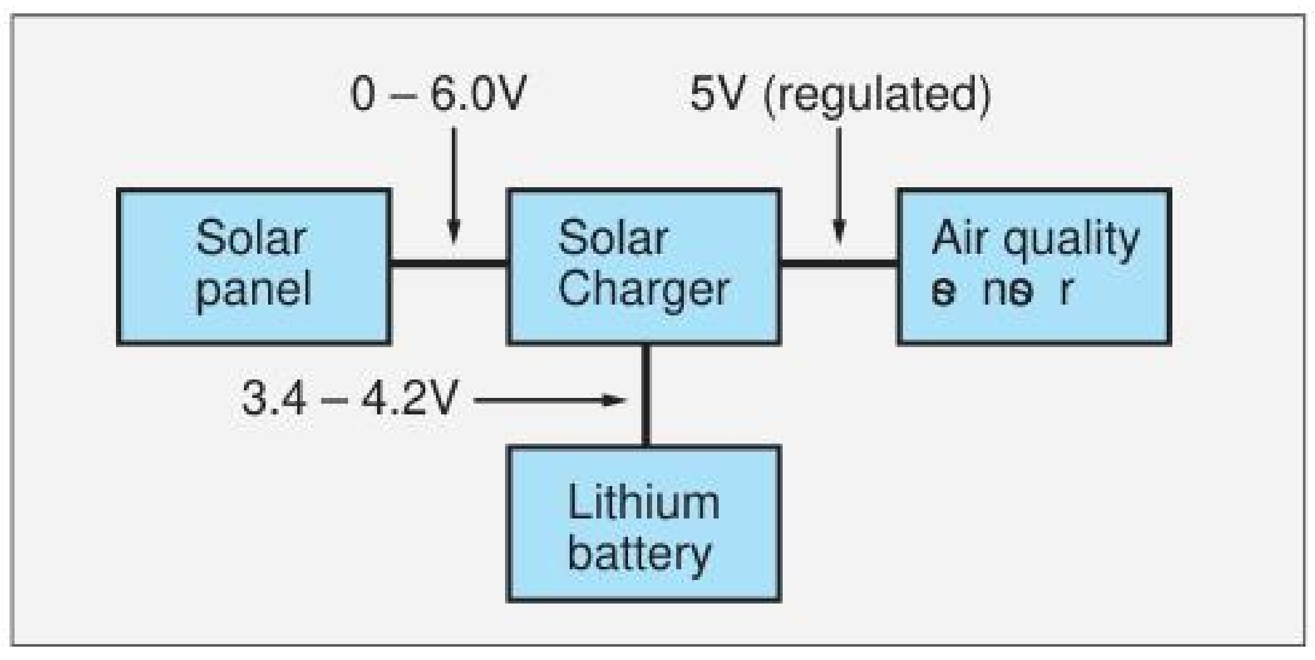


Fig.3. Air-quality sensor block diagram.

the previous article to confirm everything is well. When using the PICkit debugger, it is best to have the board powered rather than rely on power applied from the debugger itself.

To power the board, two options are provided. Header pins HDR1A and HDR1B allow for wire or croc-clip connectors, while the more robust method would be to use a mains power supply connected to the DC Barrel Jack socket CON1, which has an inner positive pin. You can supply the board with a voltage from 9V to 24V DC, with 9V to 12V recommended to avoid increasing the heat dissipated by the linear regulator (IC1). The Microchip programming interface is connected to HDR2, with the MCLR pin aligned with the triangle image on the PCB.

We did make one small change to the board after assembly – the power LED (LED2) is quite bright when using the specified part. A 4.7kΩ resistor provided a less distracting indication, but this is really a personal taste decision, and does depend on the specific LED you use. We settled on 4.7kΩ as it was a value already used on the design.

Our first project

Last month, we made a very simple, contrived project using the Microchip Code Composer tool (MCC), just to check software tools had been installed correctly, and to give the board a very basic test. Over the next few articles we will build a real project.

By a timely coincidence, a need came up for a voltage monitor to help study the performance of a solar-powered air quality sensor currently in early design stages. We wanted to monitor the voltage generated by the solar panel, and the voltage on the small lithium-ion rechargeable battery used to power the sensor. At a block diagram level, the system looks as shown in Fig.3.

The solar panel will provide an output of 6V DC under clear sky conditions, and feeds a small charger module that will deliver a charge to the lithium-ion battery, and boost the battery voltage from 3.7V typical to a regulated 5V DC output. On a good day, the battery will be fully charged by sunset. On a very cloudy day, there may be only a small amount of charge delivered to the battery. While it would be easy to use a large battery and a large solar panel, we wanted to try a number of setups to see if we could minimise the panel and battery sizes, while still being able to provide power under all weather conditions.

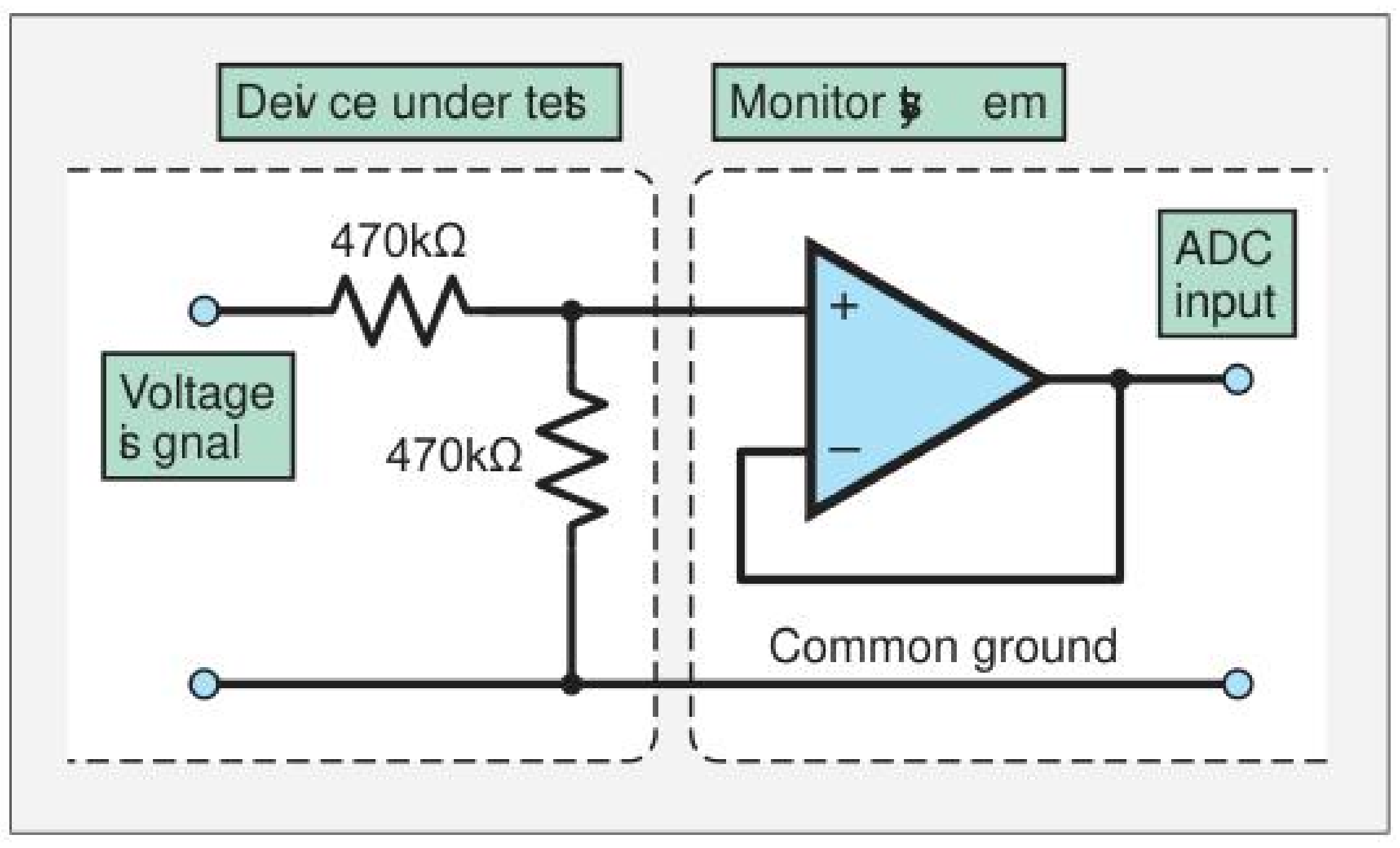


Fig.4. Op amp circuit.

To do this, we decided to create a circuit that would monitor the solar panel voltage and battery voltage, taking a reading every five minutes. The monitor circuit would be powered independently, store data to an SD Media card and make the data available through a Wi-Fi interface. The measurements would be transmitted over a serial link too, primarily to help with development testing. The board will be fitted into a test enclosure with the solar-powered device, and then left outdoors facing the sun. As the intent is to leave this running for potentially months at a time, the monitor board will be powered from a mains DC power supply, and a long power cable.

These requirements fit the capabilities of our development board very well. As we are using the SD Media and Wi-Fi interfaces, the board's electronics will need to be operated at 3.3V (so JP1 will be fitted.) We will need two ADC inputs to monitor the voltages, and so we will use pins RA0 and RA5, which connect to ADC inputs AN0 and AN5 respectively. Serial output will be on the USB serial interface, which uses pins RB2 and RB3.

So far so good, but a problem becomes apparent. With the board running at 3.3V, the analogue voltages on the ADC inputs are limited to between 0V and 3.3V. Both the solar panel (6V maximum) and the lithium-ion battery (4.2V maximum while charging) exceed this voltage. We will need to divide these voltages down before sending them to the ADC inputs on the processor. As we do not have a high accuracy requirement, a simple 'divide-by-two' resistor network using standard 5% parts is appropriate.

Now, we have a new problem. The ADC input pins require a voltage that has a relatively low source impedance – 2kΩ maximum, according to the datasheet. We could achieve that easily enough – two 1kΩ resistors – but these resistors would add additional, continuous drain on the sensor's battery of around 3mA. Given that the sensor is a low-power device with an average current consumption of 15mA, this would add an unacceptable load, and invalidate our testing.

We need to add a buffer in front of the ADC input so we can use a much higher value resistor divider. The circuit to do that is an op amp configured as a unity-gain amplifier. The circuit we need to construct is very simple, requiring the addition of just four 470kΩ resistors, two for each voltage measurement to the op amps, configured as shown in Fig.4. You can see our wiring setup in Fig.5. We sacrificed a few hook-up leads here rather than solder to the development board's header pins, but this is just a personal choice. The resistor divider circuit on the solar panel and battery now add only 5μA additional current drain from the sensor's power source, so will not impact the measurements we are taking. The unity-gain amplifier has a very low output impedance, making it suitable for driving the ADC input directly.

Now we understand the hardware setup, let's re-visit exactly what it is we want our monitor device to do, so we have a clear set of requirements to work with.

Project requirements

- At five-minute intervals, read the solar panel voltage and the battery voltage.
- Output the voltages read over the UART port connected to the UART-to-USB converter IC.
- Each data sample should be time stamped.

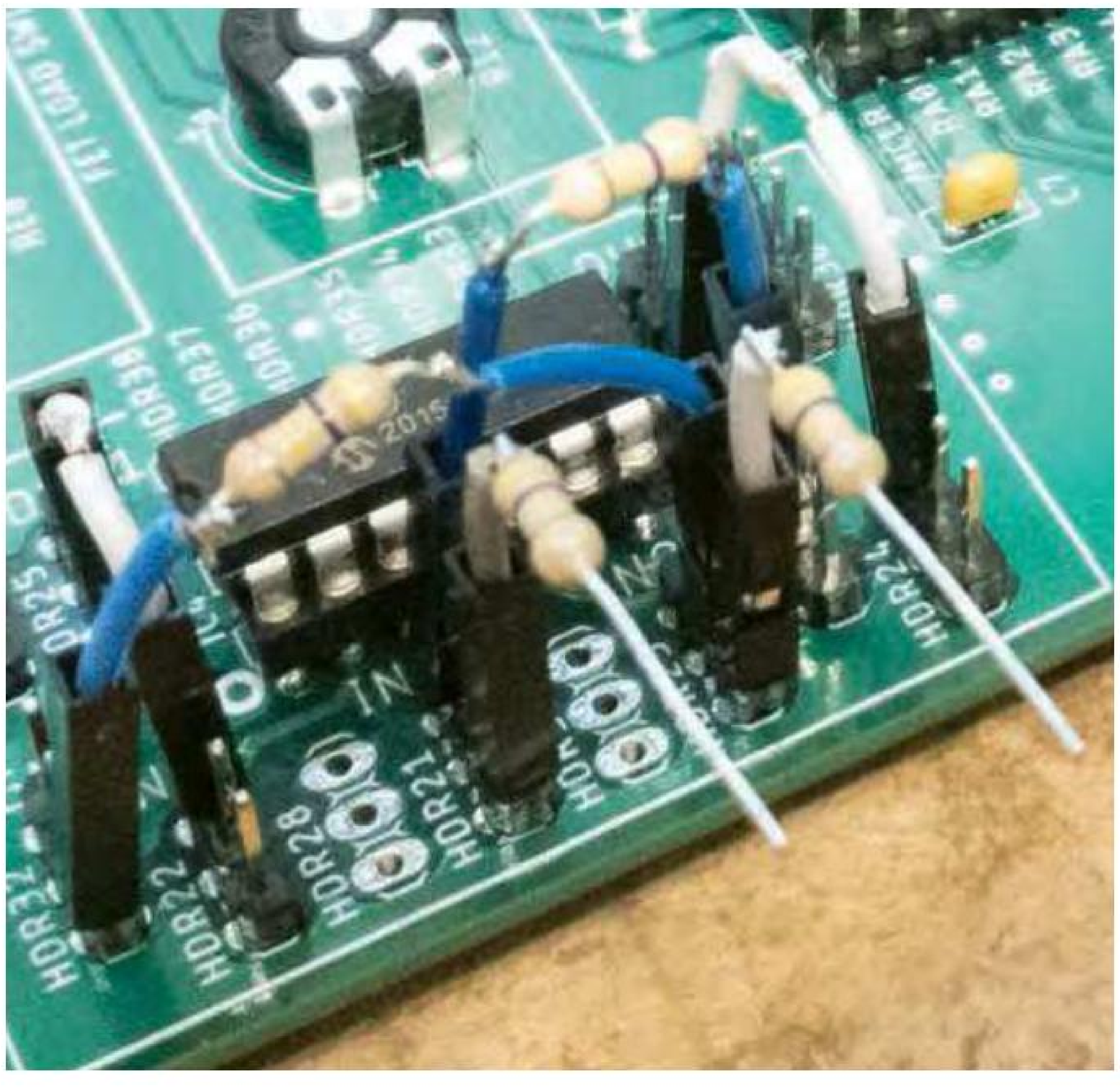


Fig.5. Wiring up the op amp interface.

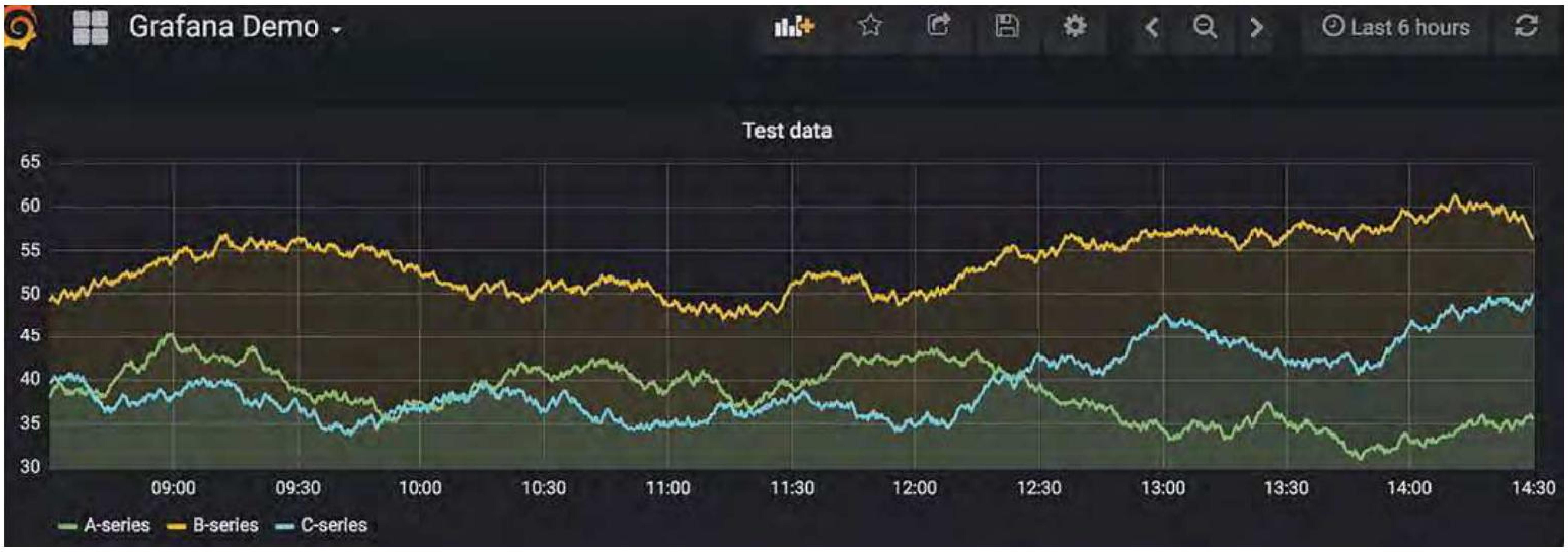


Fig.6. Example of data graphed using freely available tools.

- Write the voltages read to a text file on the SD Media card.
- As a stretch goal, record temperature and humidity inside the enclosure at the same time.
- Provide a Wi-Fi interface so that the monitor can be connected to an access point and make the data available remotely, through the home network or the Internet.
- The monitor should be self-powered, so there is no unacceptable current drain on the system being monitored.

That's seven simple requirements, although the Wi-Fi requirement is quite vague, and we will leave it vague until we understand the full capabilities of the ESP-01 Wi-Fi interface. We would ideally like to be able to 'push' our measurements to an online database and produce a nice user-friendly graphical display accessible via the Internet, like the graph shown in Fig.6. Should that prove to be too challenging, a facility to be able to download the datafile from the SD Media card over the home network would suffice. How far we get will depend on how simple the Internet software tools are to use. We suspect, however, that we are heading down an interesting rabbit hole! Online tools for receiving, storing and presenting data from Internet connected sensors have been growing year on year, and the services available for free or very low cost are numerous.

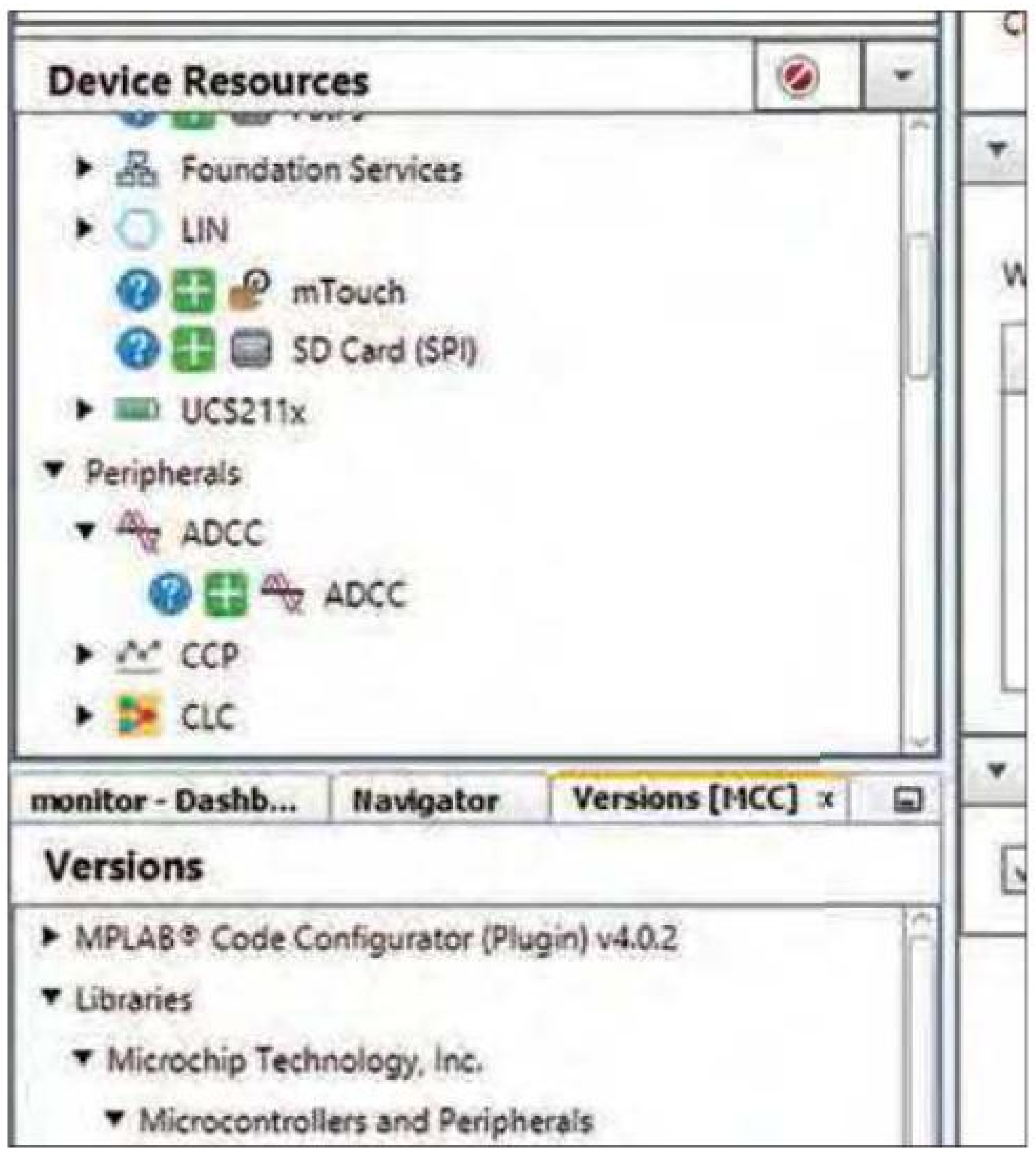


Fig.7. Adding the ADC module from MCC.

Although the example project we are creating here is specific to our particular set of requirements shown above, the inclusion of monitoring temperature and humidity is a general environmental sensor requirement that can be adapted to many uses that you may find appropriate, which is why we included it as a requirement here.

Starting the design

With that above set of requirements, we can start by working out what resources we need from the processor. We will start small by working to address the first three requirements. The remaining ones can be bolted on once the basic sensing setup has been confirmed to work. Now our software requirements are quite simple:

- Two-channel ADC reading library
- UART library
- One-second timer, to provide a timestamp
- Five-minute timer, to trigger sample sensing.

The application itself will be quite simple in operation. The one second timer will trigger an interrupt routine that will update a 32-bit counter. The five-minute timer will trigger an interrupt routine that will read the two voltages, and set a flag indicating that new data is available. The main loop of the program will wait for the flag to be set, and when it is, it will clear the flag and output the data over the UART.

It really is that simple. The tricky part is writing the ADC and UART drivers, but this is where MCC comes to our rescue – or at least, that's what the marketing department tell us. Let's find out!

Building an application

We start in MPLAB-X by creating a project:

- From the top-left menu bar, select File, then New Project, then click Next.
- Under Device, select our processor, the PIC18F47K42, followed by Next.
- Select the XC8 compiler, (v2.32 if you have more than one installed) followed by Next.
- Now select a Project Location where you would like your files to live, and then go back to Project Name and give a name of your choice – we went with 'monitor'.
- Click Finish.

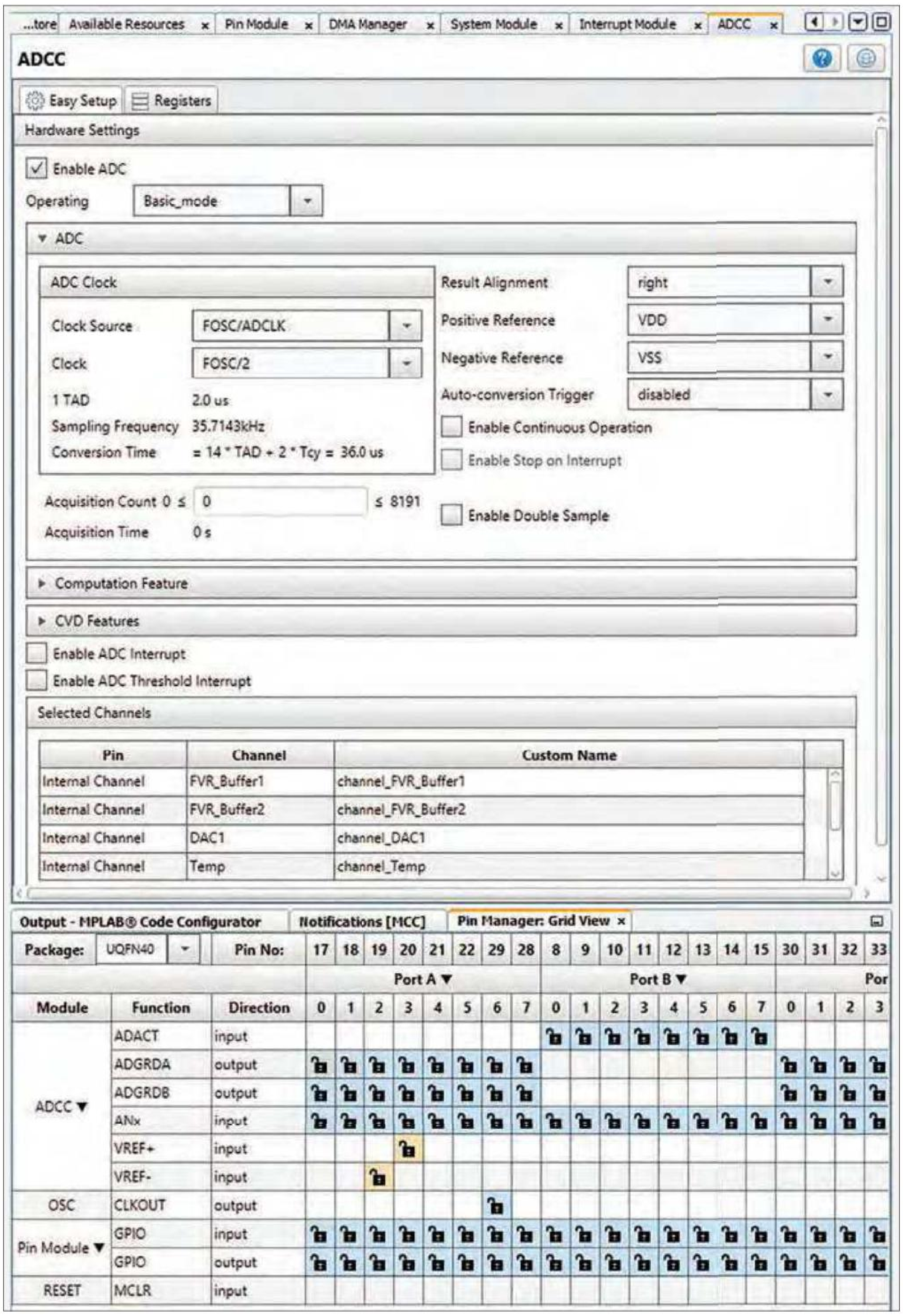
At this point we have created the project files, but no source files – not even an empty **main.c** – so let's start by using MCC to create the ADC driver, customised to our needs:

- Click on the MCC icon, followed by Save.
- Click the triangle next to the ADCC entry in the Device Resources panel, and then click on the green plus icon, as shown in Fig.7.

After a few seconds the main panel of MPLAB-X will update, showing the settings page for the ADC, and also adding an ADC section to the Pin Manager Grid View, as shown in Fig.8.

We must now assign the two pins we want to use as ADC inputs within the Pin Manager dialogue. On the row 'ANx', click the lock icon under pins PortA 0 and 5. The locks should change to green, as in Fig.9.

The dialogue above the Pin Manager view shows the basic settings for the ADC peripheral. To make any changes here we would really need to dive into the datasheet to understand the consequences of any changes, but by default these initial settings will be good enough. We can now click the 'Generate' button next to the 'Project Resources' dialogue box to convert our mouse clicks into source code.



ADCC

Hardware Settings

☑ Enable ADC

Operating: Basic_mode

ADC

ADC Clock

Clock Source: FOSC/ADCLK

Clock: FOSC/2

1 TAD: 2.0 us

Sampling Frequency: 35.7143kHz

Conversion Time: = 14 * TAD + 2 * Tcy = 36.0 us

Acquisition Count 0 ≤ 0 ≤ 8191

Acquisition Time: 0 s

Result Alignment: right

Positive Reference: VDD

Negative Reference: VSS

Auto-conversion Trigger: disabled

☐ Enable Continuous Operation

☐ Enable Stop on Interrupt

☐ Enable Double Sample

Computation Feature

CVD Features

☐ Enable ADC Interrupt

☐ Enable ADC Threshold Interrupt

Selected Channels

Pin	Channel	Custom Name
Internal Channel	FVR_Buffer1	channel_FVR_Buffer1
Internal Channel	FVR_Buffer2	channel_FVR_Buffer2
Internal Channel	DAC1	channel_DAC1
Internal Channel	Temp	channel_Temp

Package: UQFN40

Module	Function	Direction
ADCC	ADACT	input
	ADGRDA	output
	ADGRDB	output
	ANx	input
	VREF+	input
	VREF-	input
OSC	CLKOUT	output
Pin Module	GPIO	input
	GPIO	output
RESET	MCLR	input

Fig.8. Configuring the ADC module.

After a few seconds a list of files generated is shown, as can be seen in Fig.10. Clicking on the 'Files' tab in the top left-hand corner of MPLAB-X will show the list of files, and we can double click on **main.c** to see what's been written for us. There are header files and copious comments, but the key bit of code generated is shown in Listing 1.

The `SYSTEM_Initialise()` call performs all the once-off chip configuration – setting the system clock source, configuring the ADC module, and setting pin modes to the settings we chose (or left at default) in the MCC GUI. There is an empty `while` loop where we will eventually place our application-specific code. Notice also there are two commented-out lines of code, used to enable and disable interrupts, which we will make use of once we implement the timer interrupt routines.

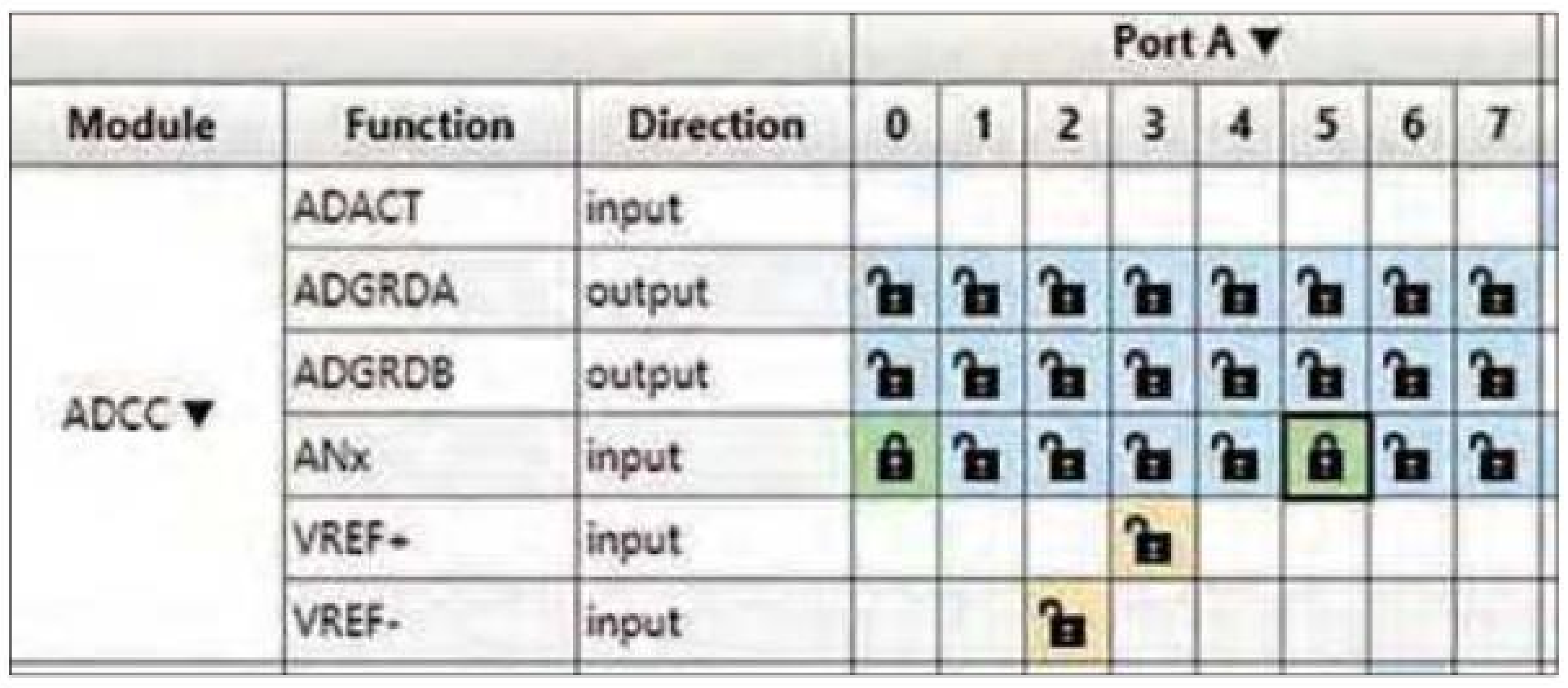


Fig.9. Assigning the ADC inputs.

Back on the 'Files' tab in the MPLAB-X GUI, click on 'mcc_generated_files' to reveal the sub-directory contents. Here you will find **mcc.c**, which contains not only the `SYSTEM_Initialise code`, but also **adcc.c** and **adcc.h**, the source files that implement our ADC driver. Opening the header file **adcc.h** reveals loads of functions, each nicely documented.

The `ADCC_StartConversion` function's description even includes exactly the code we require, which we can almost cut and paste into our main loop. The code we end up with is shown in Listing 2. It converts the ADC value to a voltage value, and outputs this data over the UART.

Note that the value returned from the ADC is not a voltage, but an ADC code. The ADC peripheral is a 12-bit converter, which means it will output a code from 0 when the input voltage is 0V up to 4095 when the input voltage is 3.3V. The software conversion to an actual voltage value, which takes into account that the signal presented to the ADC is half that of the actual voltage being measured, is handle by a single line of code:

```
solarPanel_volts = (solarPanel_
  volts * 3.3 * 2.0) / 4095.0;
```

A more important thing to note is that this program will not function as expected, in fact not at all, for two reasons. First, by default the `printf` function does not actually print anything. By a standard convention in embedded software development tools, the `printf` function does all the formatting and conversion magic, but it ultimately calls the `putch` function to send each text character out of the processor. And again, by convention, the default implementation of `putch` is an empty function. The idea is that every

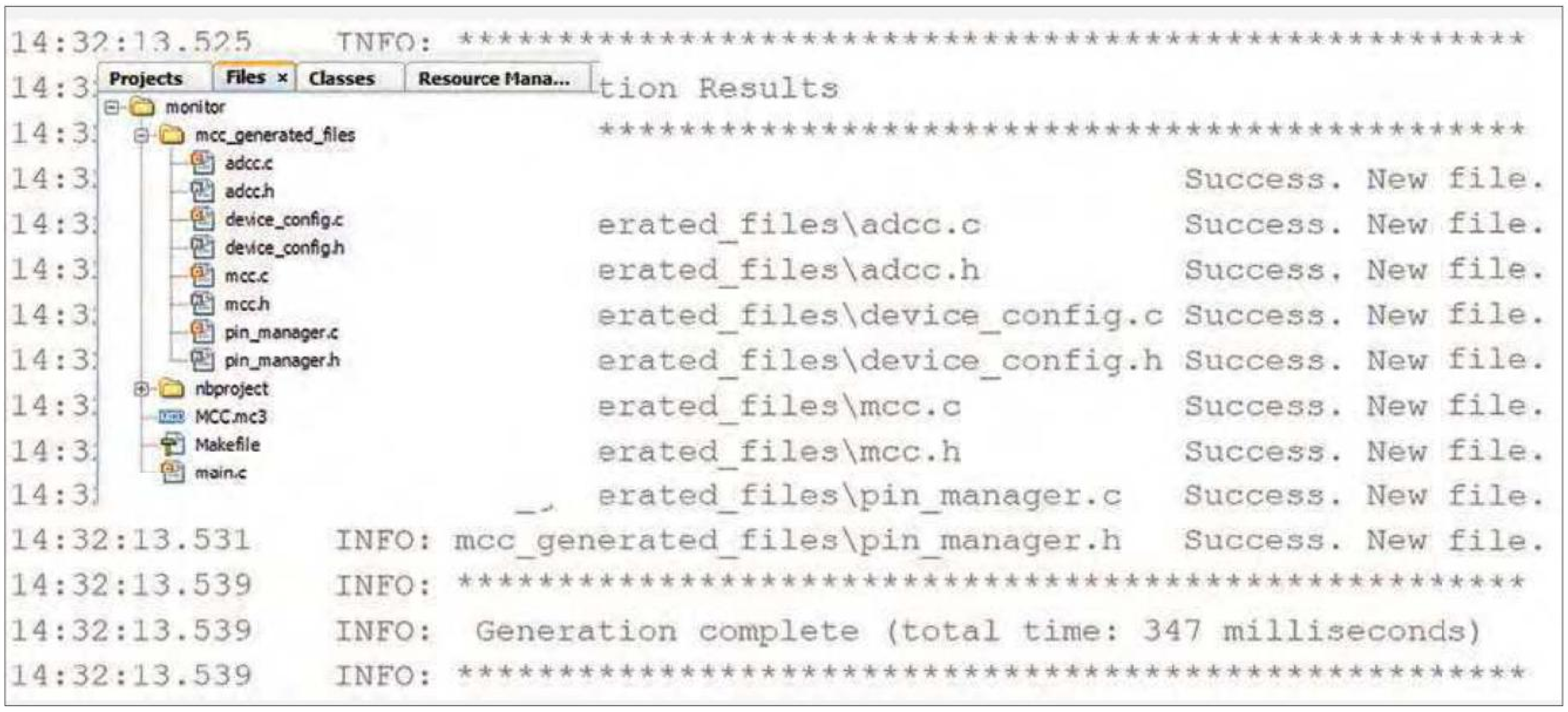
Listing 1. **main.c** auto-generated source code.

```
void main(void)
{
   // Initialize the device
   SYSTEM_Initialize();

   // Enable the Global Interrupts
   //INTERRUPT_GlobalInterruptEnable();

   // Disable the Global Interrupts
   //INTERRUPT_GlobalInterruptDisable();

   while (1)
   {
     // Add your application code
   }
}
```



```
14:32:13.525    INFO: *****************************************************
14:3                         tion Results
14:3                         **********************************************
14:3                                                      Success. New file.
14:3                         erated_files\adcc.c          Success. New file.
14:3                         erated_files\adcc.h          Success. New file.
14:3                         erated_files\device_config.c Success. New file.
14:3                         erated_files\device_config.h Success. New file.
14:3                         erated_files\mcc.c           Success. New file.
14:3                         erated_files\mcc.h           Success. New file.
14:3                         erated_files\pin_manager.c   Success. New file.
14:32:13.531    INFO: mcc_generated_files\pin_manager.h   Success. New file.
14:32:13.539    INFO: *****************************************************
14:32:13.539    INFO:  Generation complete (total time: 347 milliseconds)
14:32:13.539    INFO: *****************************************************
```

Fig.10. MCC-generated files.

embedded platform will have its own non-standard output hardware requirements, so it is down to us to implement it. Fortunately, it is very simple to do this, and MCC will help us out.

The second issue is that we have not yet specified the oscillator configuration of the processor, and the default configuration created by MCC assumes an external high-frequency crystal is fitted.

Listing 2. **main.c**, updated with our application code.

```
void main(void)
{
   adc_result_t solarPanel_volts_adc;
   adc_result_t battery_volts_adc;
   double solarPanel_volts;
   double battery_volts;

   // Initialize the device
   SYSTEM_Initialize();

   // Enable the Global Interrupts
   //INTERRUPT_GlobalInterruptEnable();

   // Disable the Global Interrupts
   //INTERRUPT_GlobalInterruptDisable();

   ADCC_Initialize();

   while (1)
   {
     ADCC_StartConversion(channel_ANA0);
     while(!ADCC_IsConversionDone());
     solarPanel_volts_adc = ADCC_GetConversionResult();
     solarPanel_volts = (double)solarPanel_volts_adc;
     // Convert ADC value to volts, compensate for divide by 2
     solarPanel_volts = (solarPanel_volts * 3.3 * 2.0) / 4095.0;

     ADCC_StartConversion(channel_ANA5);
     while(!ADCC_IsConversionDone());
     battery_volts_adc = ADCC_GetConversionResult();
     battery_volts = (double)battery_volts_adc;
     // Convert ADC value to volts, compensate for divide by 2
     battery_volts = (battery_volts * 3.3 * 2.0) / 4095.0;

     // Print the values over the serial port
     printf(“Battery voltage: %1.2f, Solar voltage: %1.2f\r\
         n”,battery_volts, solarPanel_volts);

   }
}
```

Let's correct that now. In the Project Resources dialogue, clicking on System Module will bring up the settings dialogue, as shown in Fig.11. Under the INTERNAL OSCILLATOR section, change:

- Oscillator Select from EXTOSC to HFINTOSC
- HF Internal Clock setting to 16_MHz
- The Clock Divider to 1.

Note at the top, where we are informed that the Current System clock is now 16MHz. Not the fastest the processor can run, but fast enough for our needs. Now click the Generate button in the Project Resources dialogue. In the Output tab of MPLAB-X's central window, you can see that the auto-generated files have been updated, but the changes we made have been preserved. The MCC tool applies some intelligence when changes are made; it will avoid modifying or deleting hand-written code.

To finish off (hopefully – we haven't tried running the code yet!) let's implement that `putch` function.

In the Device Resources dialogue, double-click on UART, then click on the green plus icon besides UART1. This will open up the UART1 settings page.

Change the Baud Rate to 115200 (we like fast communications!) and, under Software Settings, click on the Redirect STDIO to UART button. This should connect our `printf` function to the UART.

Finally, we need to select the pins we will use for transmit data and receive data. Click on the Pin Manager: Grid View tab, scroll down until the UART1 Module is visible, and select Port B 3 as RX1, and Port B 2 as TX1. As some Port B pins are by default mapped to analogue inputs, go to the Project Resources tab, click on Pin Module to bring up its settings page. On the RB2 column, un-tick the Analog check box. Click the Generate button for the final time to create the revised source code.

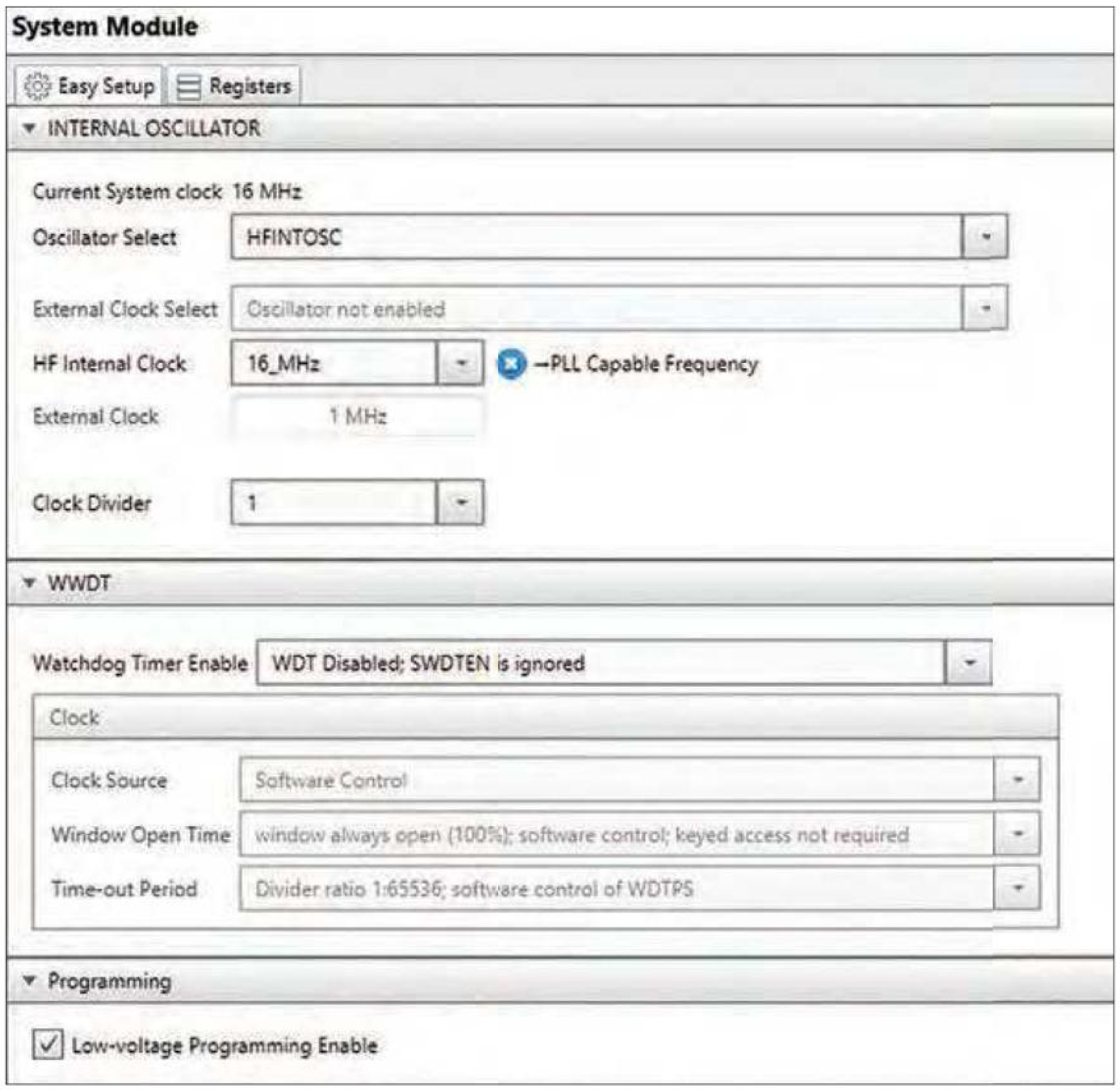
With the source code revised, we can click on the Notifications [MCC] tab to view any hints offered during the source code generation. Yes, there is one important hint: 'Selected Tad (125.0ns) ≤ minimumTad (1.0µs). Please lower the sampling frequency!'

It would appear that at our high clock speed, the default clock input frequency to the ADC peripheral is too high. Choosing an ADC clock frequency requires careful calculation when sampling quickly varying signals, but with slowly changing voltage sources, as we have here, we can be more relaxed, and guess a 'reasonable' value. We set the Clock value to FOSC/50, and the Acquisition Count to 1000 to give an Acquisition Time of 62.5µs – that should be long enough with a low impedance input signal to charge the ADC peripheral's input capacitor. We click Generate once more to revise our source code, and the notification hint goes away. We are good to go.

Running the code on the board with the debugger, we see that output is generated over the USB serial interface – great! Now, we can stop the debugger and use the 'Make and Program Device' icon to flash the code to our board, confirming that the code runs without a debugger to support it. At this point, we are ready to proceed with the remaining requirements.

Approaching the design in this way has allowed us to deal with the simpler requirements, gaining familiarity with the MCC tool before moving onto the more complicated integrations.

Last, but not least, in a first for *Practical Electronics*, a YouTube video has been produced that is a screencast of the steps described above. You can find it at: **https://youtu.be/WHZ4koDNNwU**



System Module

▼ INTERNAL OSCILLATOR

Current System clock 16 MHz

Oscillator Select: HFINTOSC

External Clock Select: Oscillator not enabled

HF Internal Clock: 16_MHz — PLL Capable Frequency

External Clock: 1 MHz

Clock Divider: 1

▼ WWDT

Watchdog Timer Enable: WDT Disabled; SWDTEN is ignored

Clock

Clock Source: Software Control

Window Open Time: window always open (100%); software control; keyed access not required

Time-out Period: Divider ratio 1:65536; software control of WDTPS

▼ Programming

☑ Low-voltage Programming Enable

Fig.11. Setting the processor clock source.

Coming up

In the next article we will add the SD Media card and Wi-Fi functionality, and transfer our design to a custom board so we can combine it with the solar charging circuit that it will monitor for the next few months.

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AUDIO OUT

By Jake Rothman

Microphone Preamplifier (for Vocoder) – Part 3

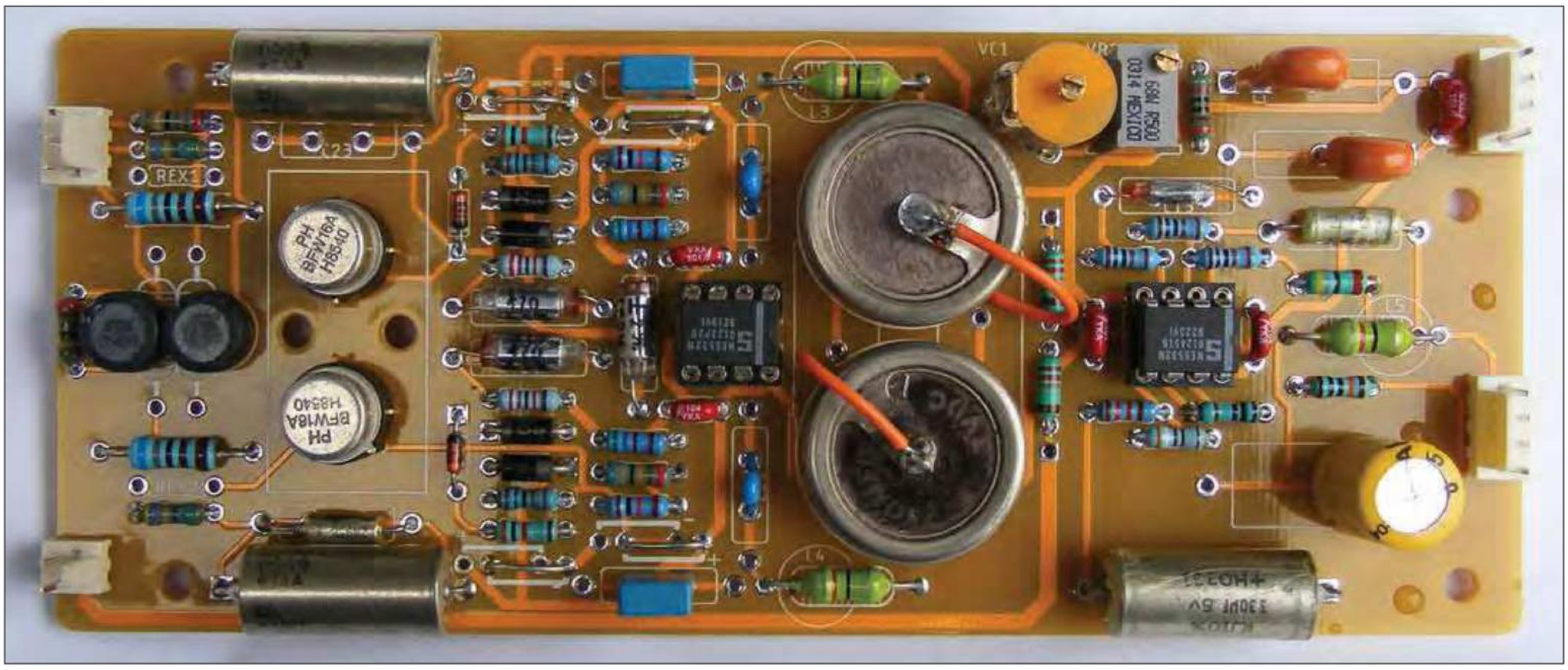


Fig.22. The assembled microphone preamplifier PCB – note the links for NPN version.

We're now in a position to carry out the construction and testing of our microphone preamplifier. The circuit is mainly direct coupled and has lots of polarised components, so mistakes can cause damage. For example, if D1 is reversed, the transistor base will be connected to the power rail and the transistor and op amp may be destroyed or less obviously, just go noisy. Reverse-polarised tantalum capacitors may go short circuit, killing connected components. So, pay attention to polarity and component orientation!

Construction

Most small components are mounted on the PCB, which is a standard, easy-to-repair, double-sided plated-through-hole design available from the *PE PCB Service* (code AO-JUL21). Mike Grindle has created a clear mirror-imaged symmetrical design. The overlay is shown in Fig.21 and the capacitors are dual outline, so either standard radial or expensive axial types can be fitted. Stuffing the board should be in the following order: resistors, chip sockets, small capacitors, preset, transistor holders, big capacitors, Molex connectors, and finally the trimmer capacitor,

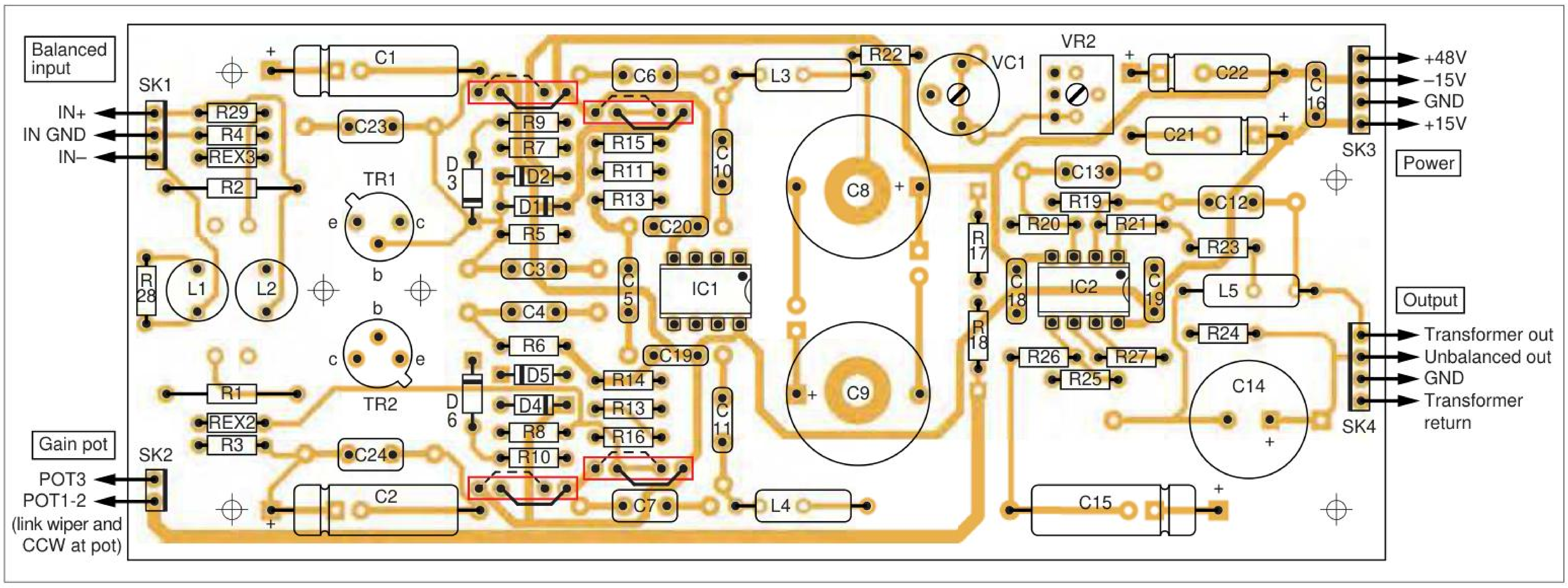

Balanced input
SK1
IN+
IN GND
IN–
R29
R4
REX3
R2
R28
L1
L2
C1
C23
TR1
e
c
b
b
c
e
TR2
R1
REX2
R3
Gain pot
SK2
POT3
POT1-2
(link wiper and CCW at pot)
C24
C2
D3
D6
R9
R7
D2
D1
R5
C3
C4
R6
D5
D4
R8
R10
C6
R15
R11
R13
C20
C5
IC1
C19
R14
R13
R16
C7
C10
C11
L3
L4
R22
VC1
VR2
C8
C9
R17
R18
C18
IC2
C19
C13
R19
R20
R21
R26
R27
R25
C12
R23
L5
R24
C14
C15
C22
C21
C16
SK3
+48V
–15V
GND
+15V
Power
Output
Transformer out
Unbalanced out
GND
Transformer return
SK4

Fig.21. Microphone preamplifier PCB overlay – take care with links and orientations if using different transistors to the BFW16A. **Important** – in red boxes only use one link: solid for NPN and dashed for PNP version of the microphone preamplifier.

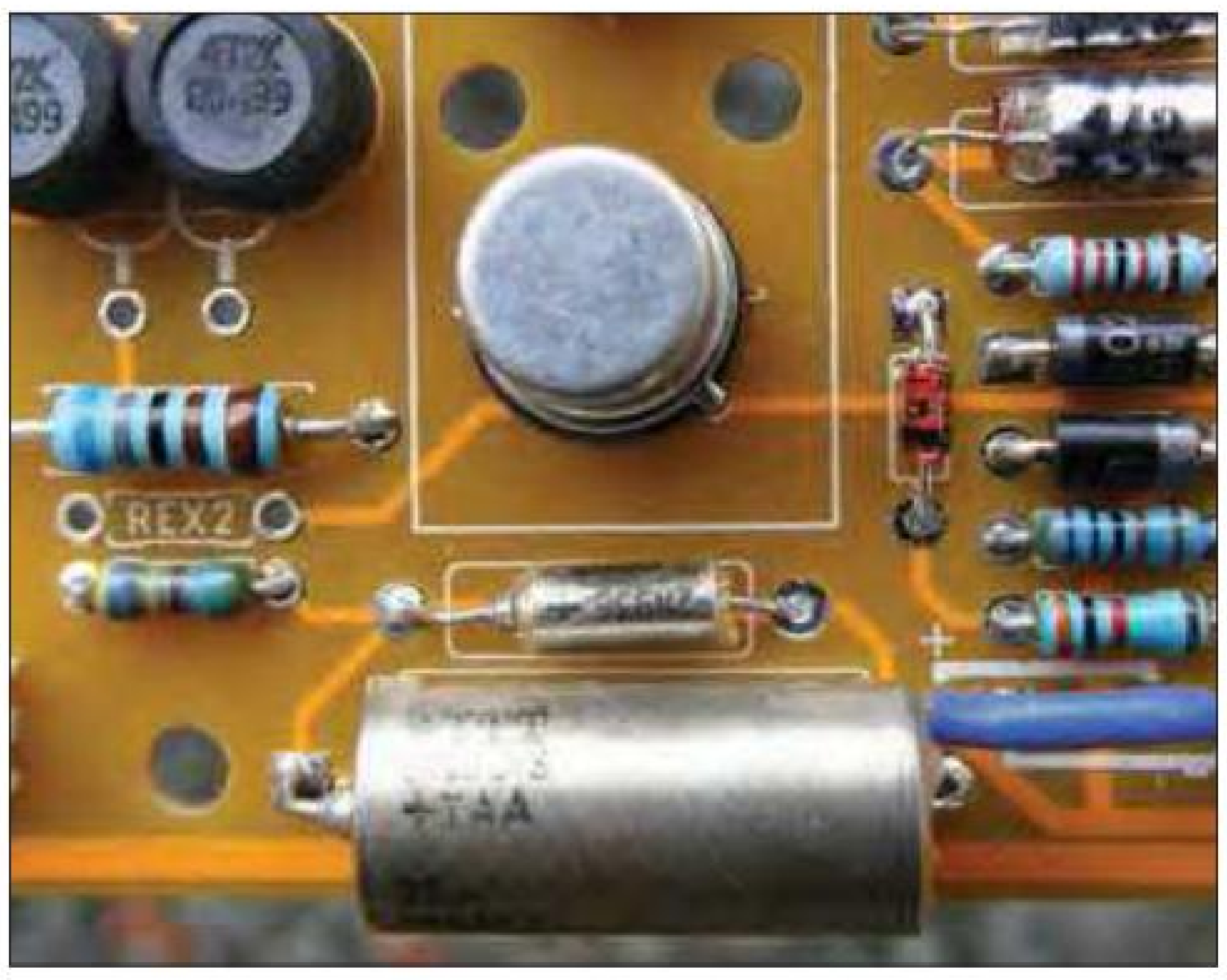


Fig.23. Occasionally the input capacitors C1/C2 (here C2, at bottom) may have values 20% apart. In this case, an extra 2.2µF capacitor (C24, shown here above C2) was added in parallel to get good matching and hence high CMRR at 50Hz.

which has a delicate adjustment screw. Several views of the completed PCB are shown in Fig.22 to Fig.25.

The big, mechanically stressed components are all panel mounted and hard-wired to the board using 7/0.1 stranded wire. No PCB-mounted pots or external plug connectors here, which often cause broken soldered joints when used on a studio floor. I just love die-cast boxes (see Fig.26), especially those by Hammond and Eddystone and use them for most of my small-batch builds because they are easy to cut and drill (much nicer than plastic or steel). Surrey Electronics always used them for their range of microphone preamplifiers and broadcast products.

A couple of other assembly points: XLR connectors have earthing tags which are useful for enclosure earthing (see Fig.27). Note how the output transformer is mounted off the board using a capacitor clip shown in Fig.28.

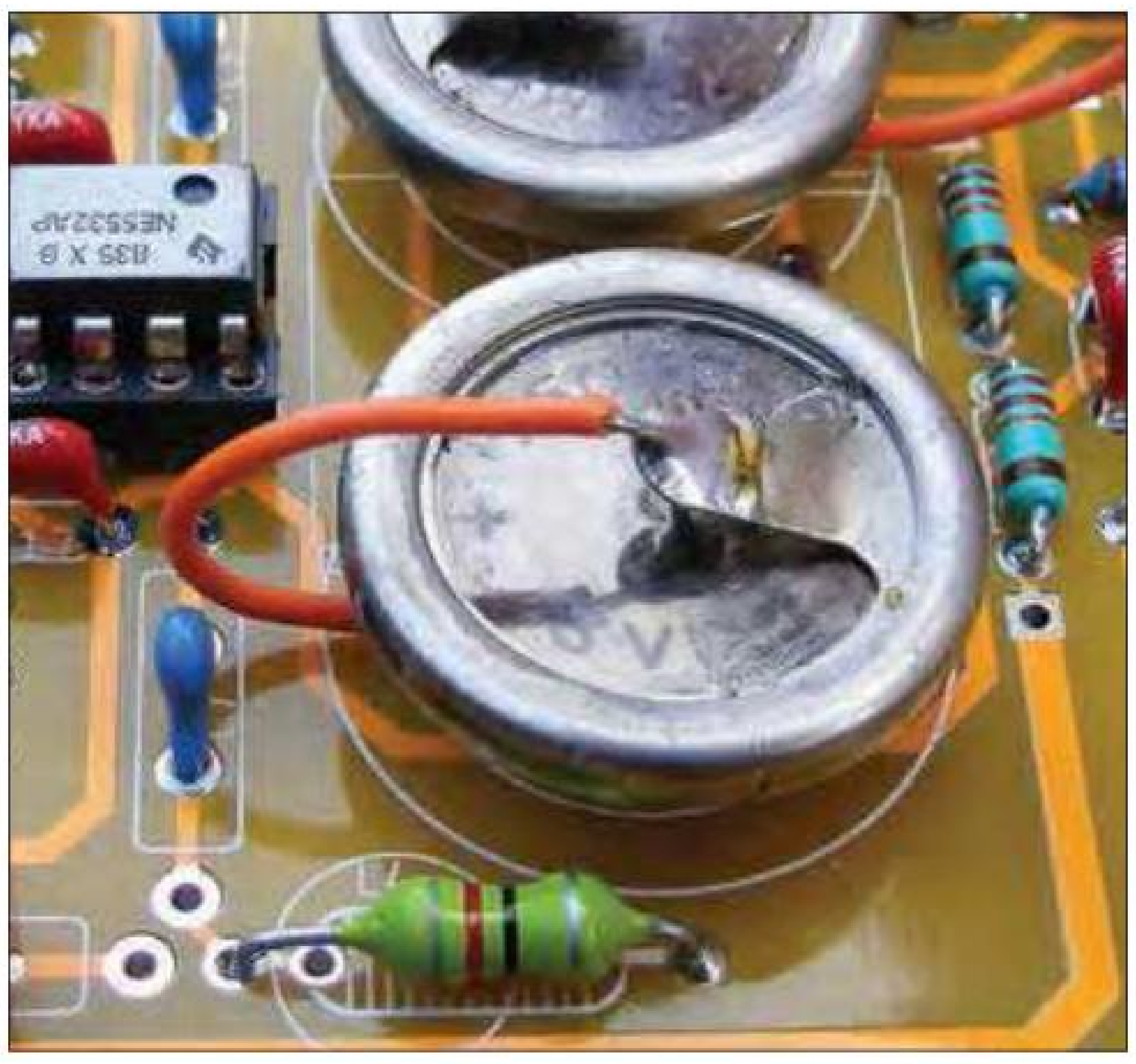


Fig.24. Note the green 82µH inductor, which looks like a strange resistor. The odd things that look like back-up batteries are Plessey Castanet tantalum capacitors.

Testing

DC conditions

At the testing stage – if possible – use a tracking plus and minus dual supply. This should be current limited to approximately 100mA. It's not nice when expensive components go up in smoke or eyeballs are damaged from flying chips when errors and high currents are combined.

The circuit runs at a standard supply of ±15V, with the transistors taking 4.2mA each and the 5532s 9mA. The total current consumption is 22 to 25mA. (The 5532s and transistors can work on an absolute maximum of ±22V supply, taking 30mA.)

An anomaly with the 5532 is that it can latch up if the rails don't rise together at turn-on. This seems to be exacerbated when capacitors are connected to the input pins, which is the situation here. I was puzzled because other op amps don't do this.

When I switched the power supply from independent to tracked, this issue went away. A solution used at Kemo Filters is to put 560Ω resistors in series with any grounded input pins or those connected to the output pin, such as in buffers, as shown in Fig.29.

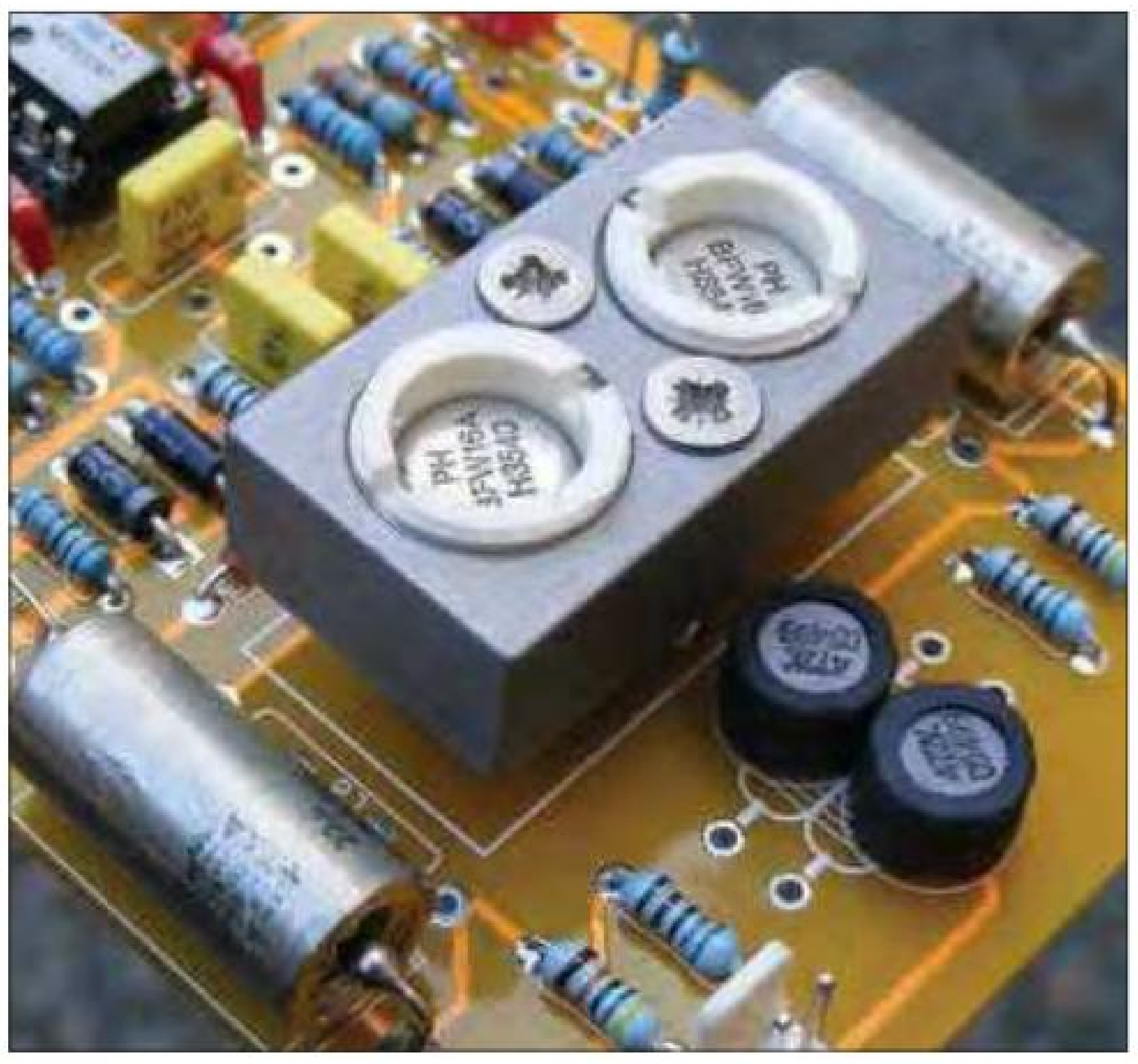


Fig.25. A thermal link was tried to ensure both transistors drifted together to minimise DC offsets. It was not worth it in this case (but is worthwhile on synthesisers).

Once powered up, check all transistor voltages and make sure the outputs of the op amps are all at zero volts, apart from the IC2 outputs which should be +0.2V approximately (due to the input bias current flowing through the 680kΩ resistors R11 and R12). If the DC conditions aren't right, the audio won't be right.

Power supply

Naturally, low noise can only be achieved if the power supply is low noise. A standard audio LM317/337 dual-rail circuit will do the job. The 48V supply is more specialised requiring a voltage doubler perched on top of the positive rail. My LM317 circuit (see *Audio Out*, *PE* March 2019) is suitable – it has low noise and while you can certainly build your own, I do still have some PCBs – see my *Audio Out Shop* advert on p.43 for contact details. Alternatively, a TL783 regulator will work.

It's best to keep the mains transformer in a separate screened (earthed metal) box to minimise mains buzz.

The circuit needs very low impedance supplies, since the power supply rejection ratio of the input transistor stages is very low. The emitters and collectors are connected to the power rails only

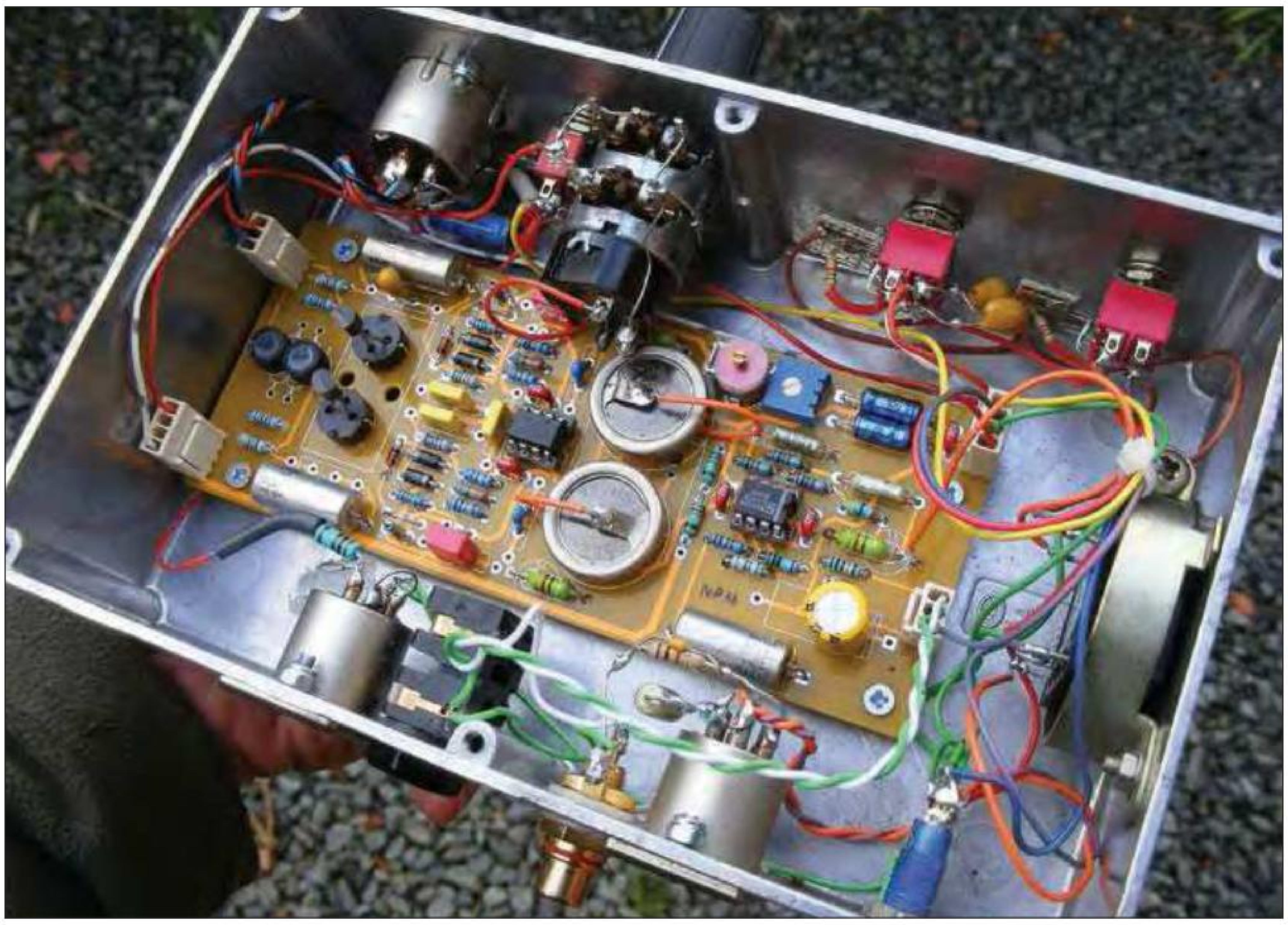


Fig.26. A single-channel microphone preamplifier fits in this die-cast box, size 187 × 120 × 55mm. (Note the PCB shown above is a slightly different prototype).

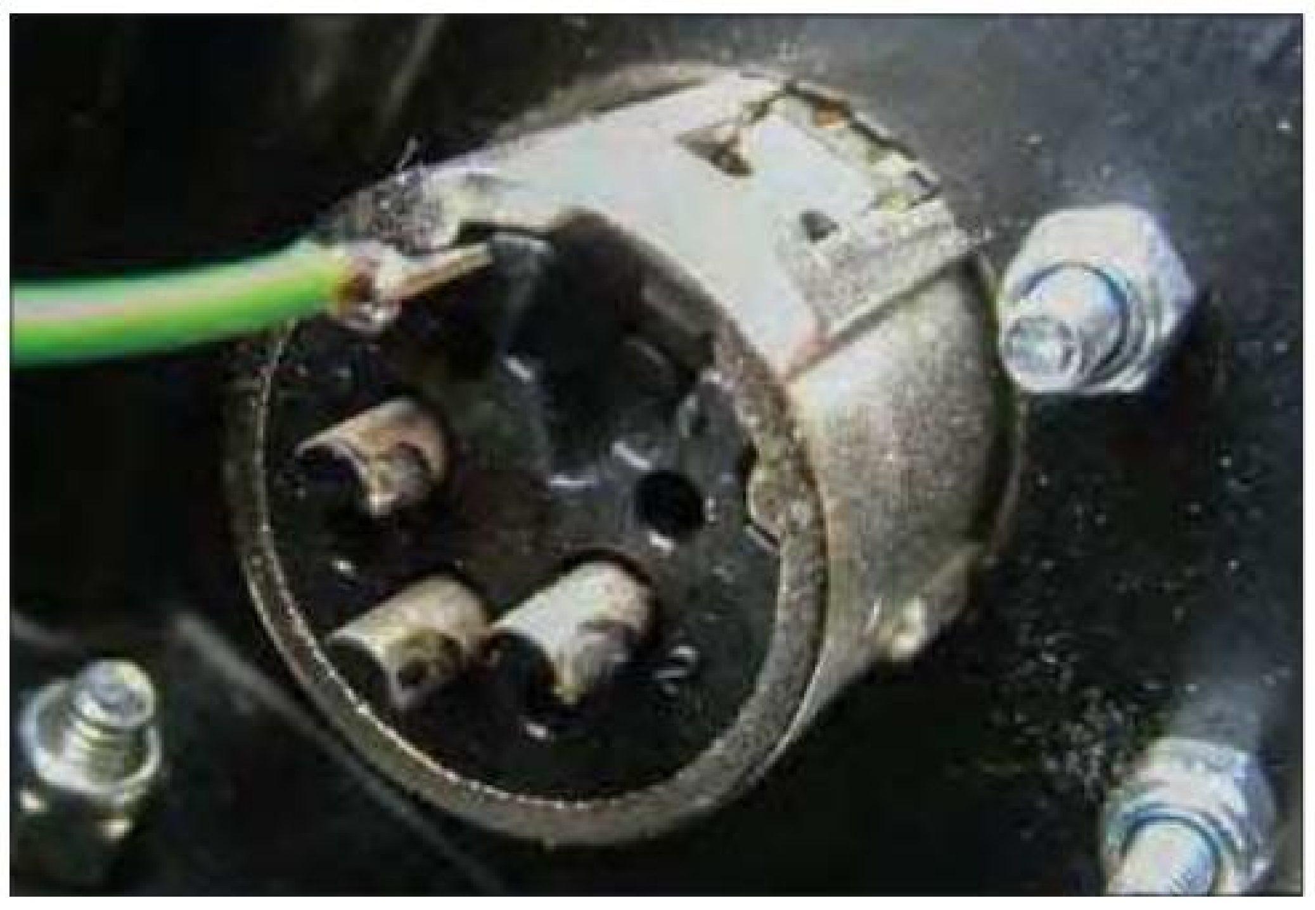


Fig.27. Metal cases can be earthed off XLR sockets via an earthing tag on the rear of the socket connected to the PSU 0V.

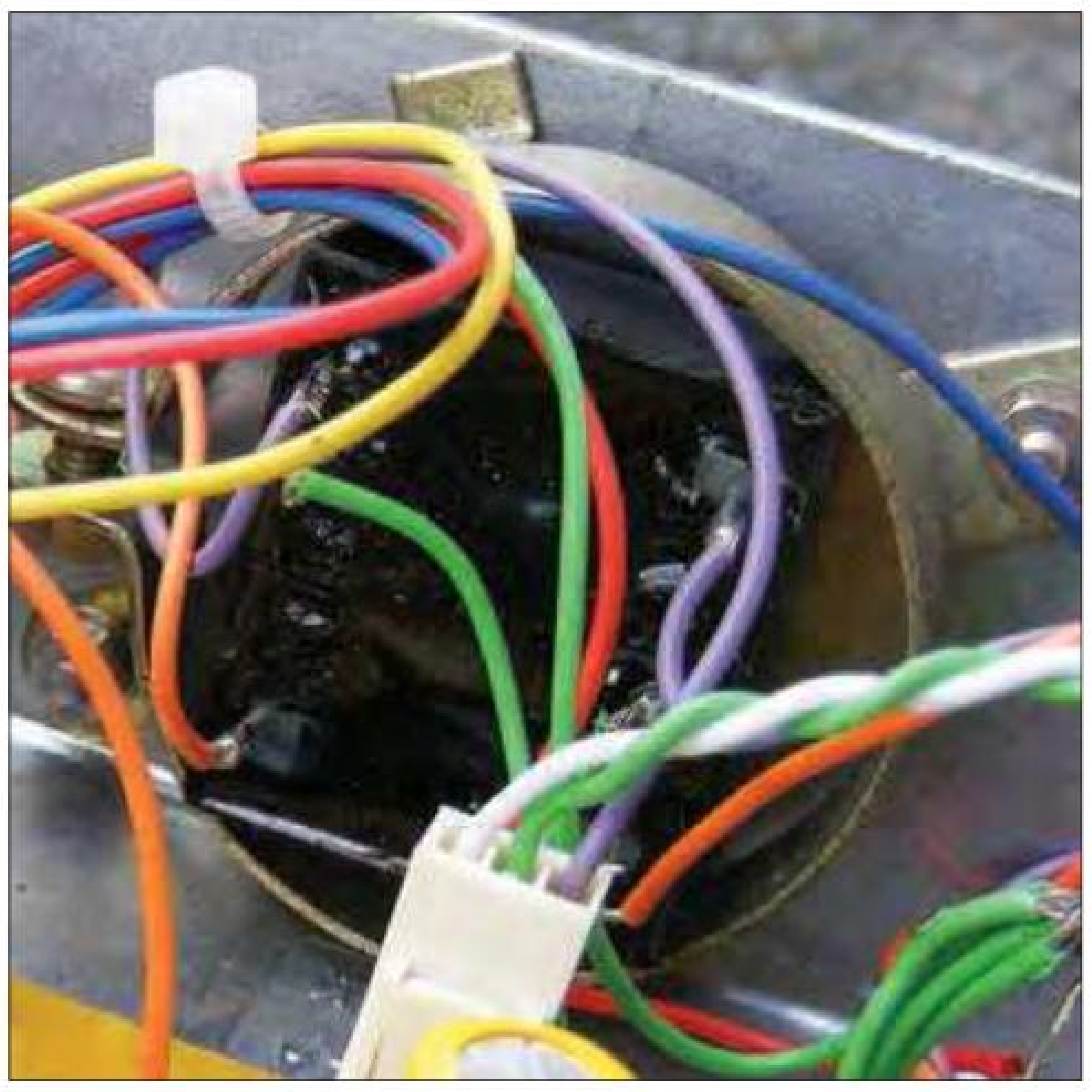


Fig.28. The output transformer is neatly clamped in a 45mm capacitor clip.

by resistors, providing an easy entry route for supply ripple. The best way to ensure a low-impedance supply is by connecting directly to the outputs of the regulators. In one design, I had 22Ω decoupling resistors feeding the board and this increased the distortion into a 600Ω load by 0.5% at low frequencies.

Noise check

Selection of the fittest has always been part of audio evolution, especially input transistors, which is why I recommend using sockets for circuits where transistors need to be selected for noise level to screen out poor devices (see Fig.33). Use a 'scope to look at both outputs of IC2 with the gain control (VR1) set to maximum, that way you can see the noise level of each transistor and pick the best ones by comparison. Do turn the power off when swapping the transistors and leave the input unloaded to achieve maximum noise for this test.

Gain check

Check the overall preamplifier gain by feeding a signal generator into the input via a small transformer or other balancing method. I use the video isolation transformer shown in Fig.30. The gain should be around 15dB (×5.6) with no R_g and 20dB (×10) with R_g = 3.69kΩ (actual value of the Blore Edwards 5kΩ dual pot with both sections wired in parallel), and finally 74dB (×5000) with the gain control fully clockwise. In the middle of rotation, it was 39dB. Check the clipping is symmetrical and the response is flat from 20Hz to 20kHz.

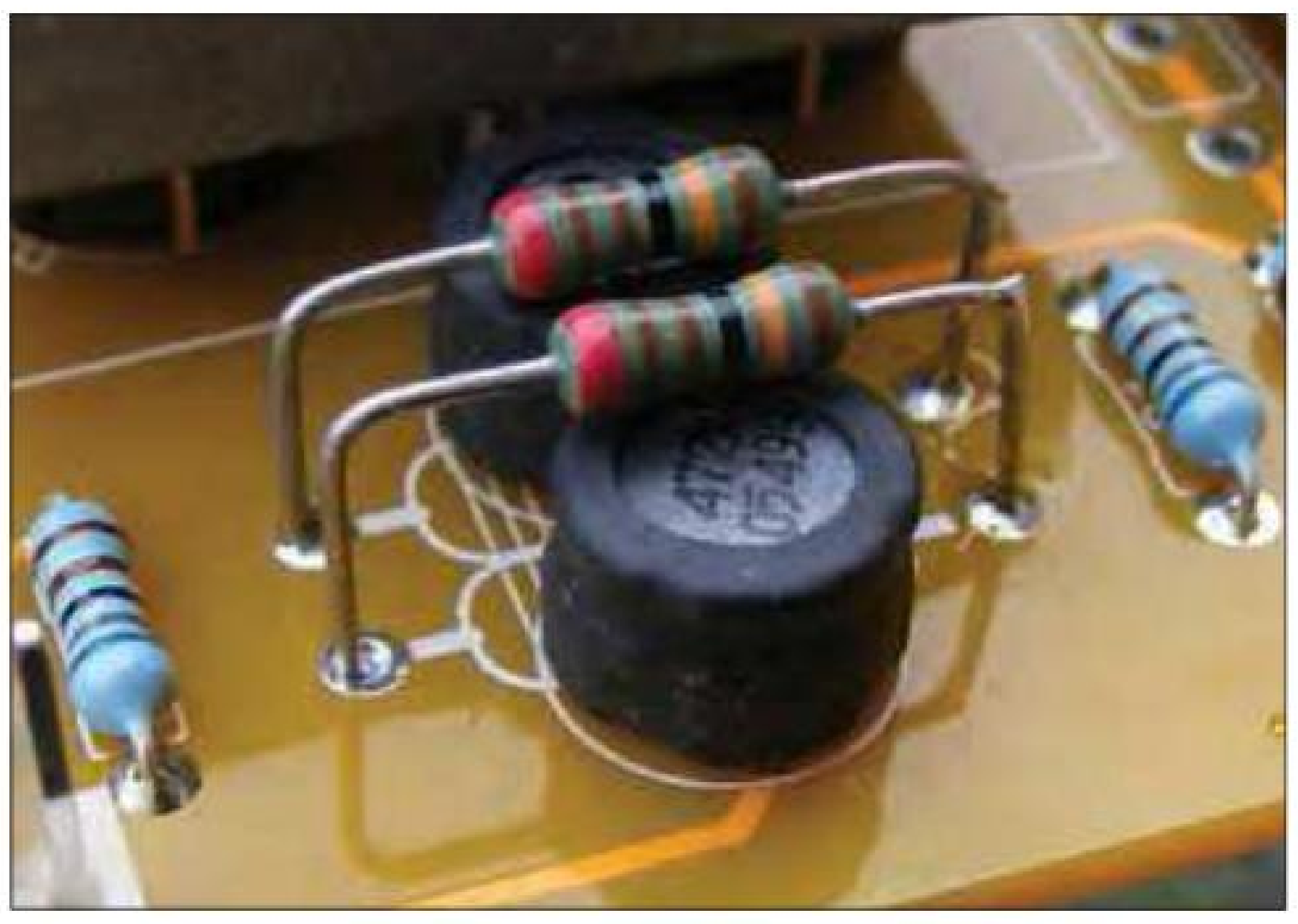


Fig.31. To reduce a minor amount of ringing on square waves, the input filter chokes L1 and L2 can be damped by wiring 1.3kΩ resistors across them (R28 and R29).

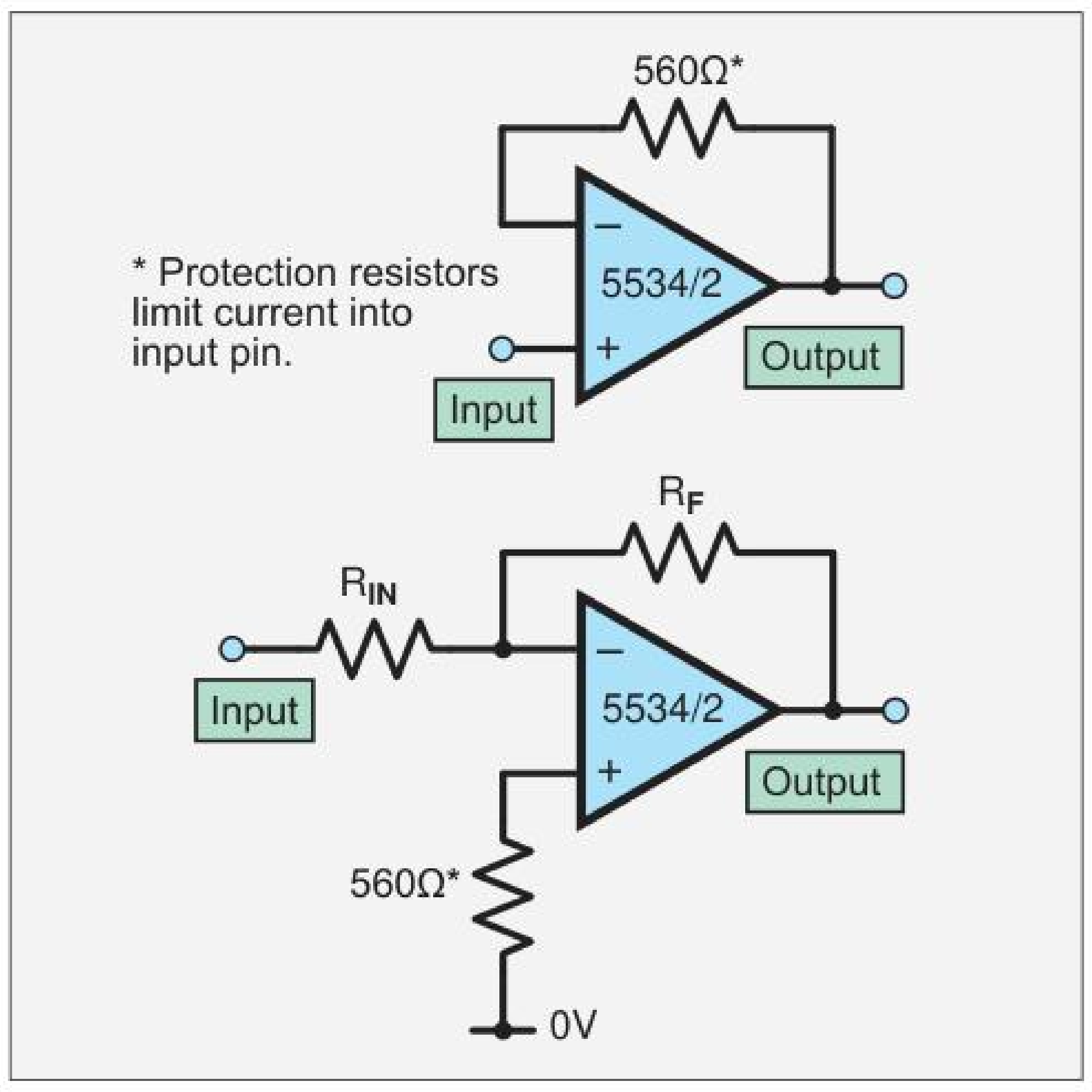


Fig.29. Inserting 560Ω resistors to prevent latch-up with 5532/4 op amps.

Square wave check

Applying a 1kHz square wave is always a good idea to check for ringing. This is necessary to optimise the Zobel network on any transformers used (See Fig.41 next month). I also found a bit of ringing on the input chokes L1 and L2; putting 1.3kΩ resistors across them on the spare inductor holes as shown in Fig.31 damped it out. These resistors are labelled R28 and R29 on the latest board but are not shown on the circuit diagram (Fig.18).

The noise should also be checked by putting two terminating resistors of 75Ω on the input pins joined together (pins 2 and 3 on the XLR socket) as shown in Fig.32. This will give a source resistance of 150Ω, mimicking a low impedance moving-coil microphone. At full gain, the noise on the output should be around $12mV_{pk\text{-}pk}$, with the low-cut filter in. (The low frequency noise is inaudible and makes it harder to read as the trace jumps about). With a metal housing, battery power and careful selection of transistors it should be possible to get the noise level lower. I've built various 'resistor terminating units' into male XLR plugs. I always recommend using metal XLR plugs to provide screening.

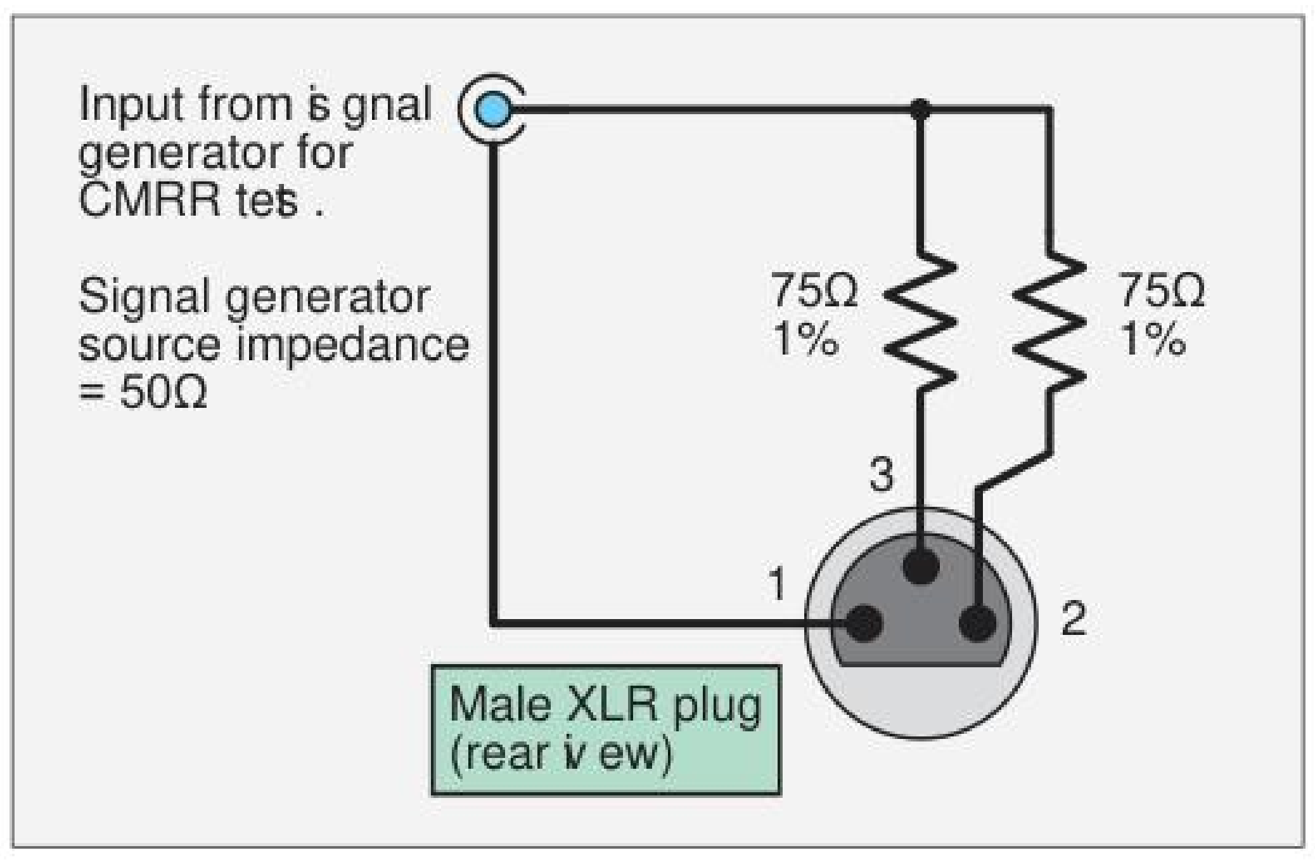

Input from signal generator for CMRR test.
Signal generator source impedance = 50Ω
75Ω 1%
75Ω 1%
3
1
2
Male XLR plug (rear view)

Fig.32. XLR termination unit provides the correct source impedance of 150Ω and enables a signal generator to be connected for CMRR testing.

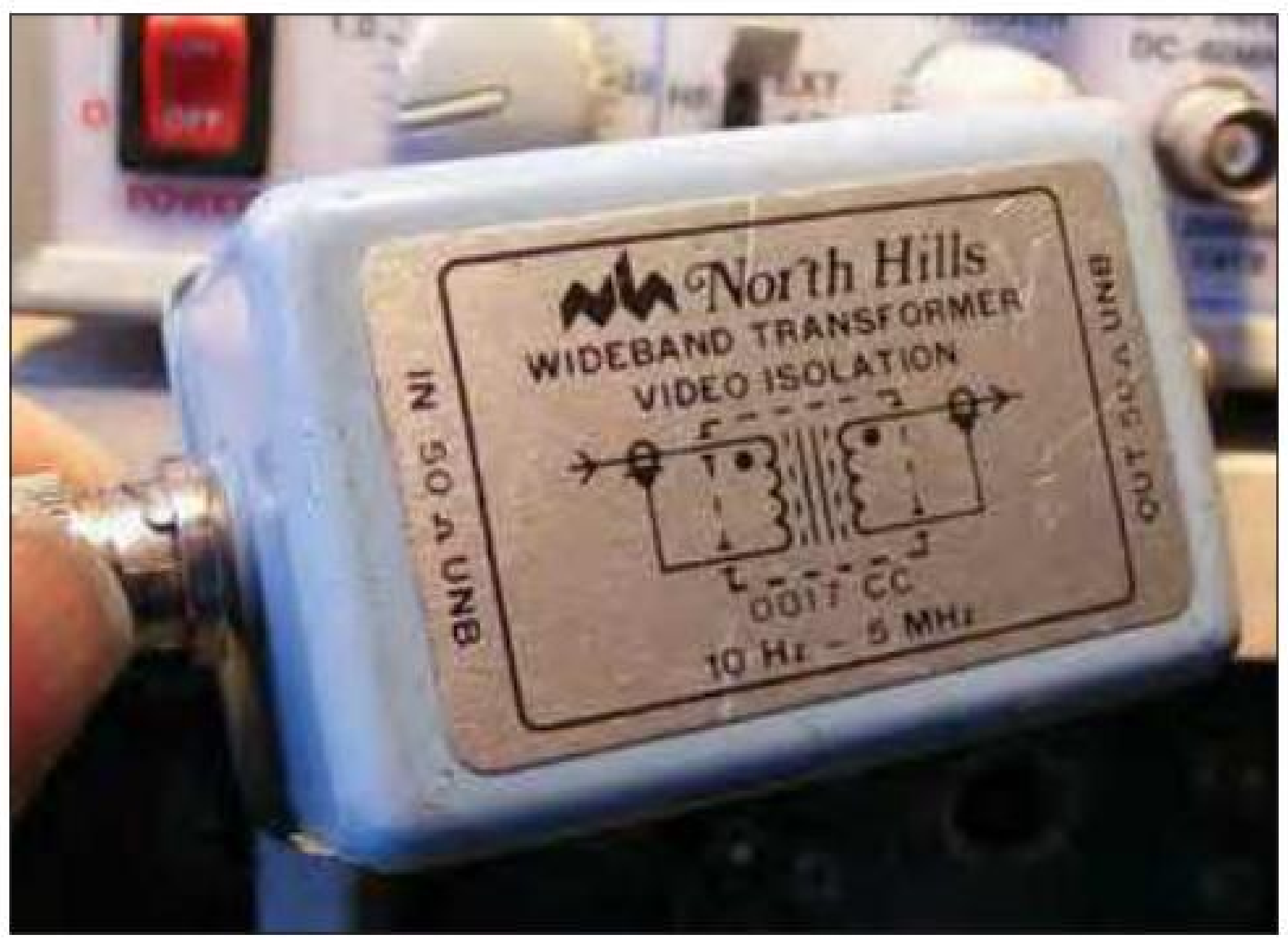


Fig.30. When testing balanced-input circuits it is necessary to use an isolating/balancing transformer between the signal generator output and preamplifier input.

Common-mode rejection ratio (CMRR) check

The CMRR can be checked by driving both inputs together in phase to see what comes out of the output, ideally nothing (see Fig.32). Unfortunately, the CMRR varies with the gain setting, a disadvantage of transformerless techniques. Because of this, I suggest checking the CMRR with the gain at around 30-40dB (two o'clock on the gain control) with an input of around 1V to $3V_{pk\text{-}pk}$. Because the gain control (R_g) only boosts gain on common-mode signals, both outputs from IC1 will remain almost unchanged at around $5V_{pk\text{-}pk}$ until the last bit of the maximum gain region. This is why the middle gain range is suggested for CMRR adjustment. If the unit is to be used at a fixed gain, say in a broadcast application, the CMRR should be optimised for this. First adjust trimmer VR2 at 1kHz for minimum output, then do a null at 9kHz with the trimmer capacitor VC1. The low-frequency CMRR at 50Hz can be optimised by putting 220nF to 2.2µF padder capacitors (C23 and C24) alternately across input capacitors C1 and C2 until a null is achieved (see Fig.23). I suggest these frequencies because most of the noise that's a problem in the field is mains related,

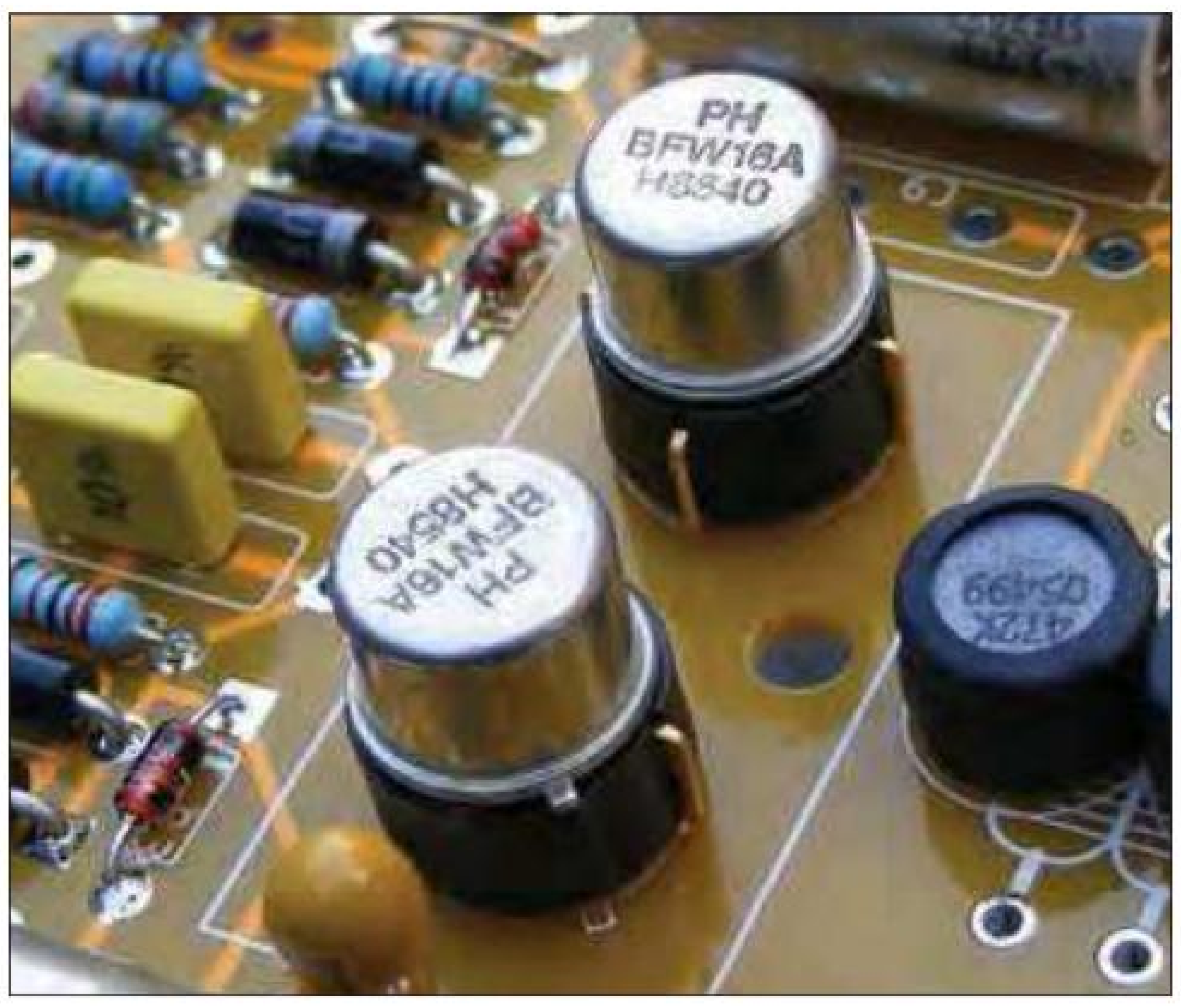


Fig.33. Transistors should be mounted in sockets so noisy ones can be easily removed. (It's also good for finding unknown gems in one's parts box) Transistors from Hitachi, Toshiba, Sanyo and Rohm seem to be the best. Only home constructors have time for this, so it is possible to improve on ready-made units.

mainly switching noise from power supplies and lighting controllers.

Surprisingly, I found the adjustment range for the trimmer was better if C13 (the trimmer parallel capacitor) was reduced to 120pF when the circuit was transferred to PCB. (There may be some stray capacitance associated with the board layout, but I doubt it'd be over 100pF. More investigation is needed!) On my boards I used C13 values ranging from 68pF to 180pF to keep the null of VC1 in the middle position. In the parts list I specified an 80pF trimmer, but I now recommend using a larger value, such as 250pF.

Mods and embellishments

Vinyl virtues

This circuit would make an effective moving-coil (MC) pick-up amplifier with RIAA equalisation incorporated, but I would have to convert my record deck to balanced output. This would make it non-standard in the Hi-Fi world, but ideally, all audio equipment should be balanced – even electric guitars! The board could be used for an unbalanced stereo moving-coil pickup head amplifier by just using the first stages and omitting IC2 and its associated components.

Phantom power

Switching phantom power can make a loud noise. It is best to slug the rise with a big electrolytic capacitor or MOSFET capacitance-multiplier circuit, as shown in Fig.34.

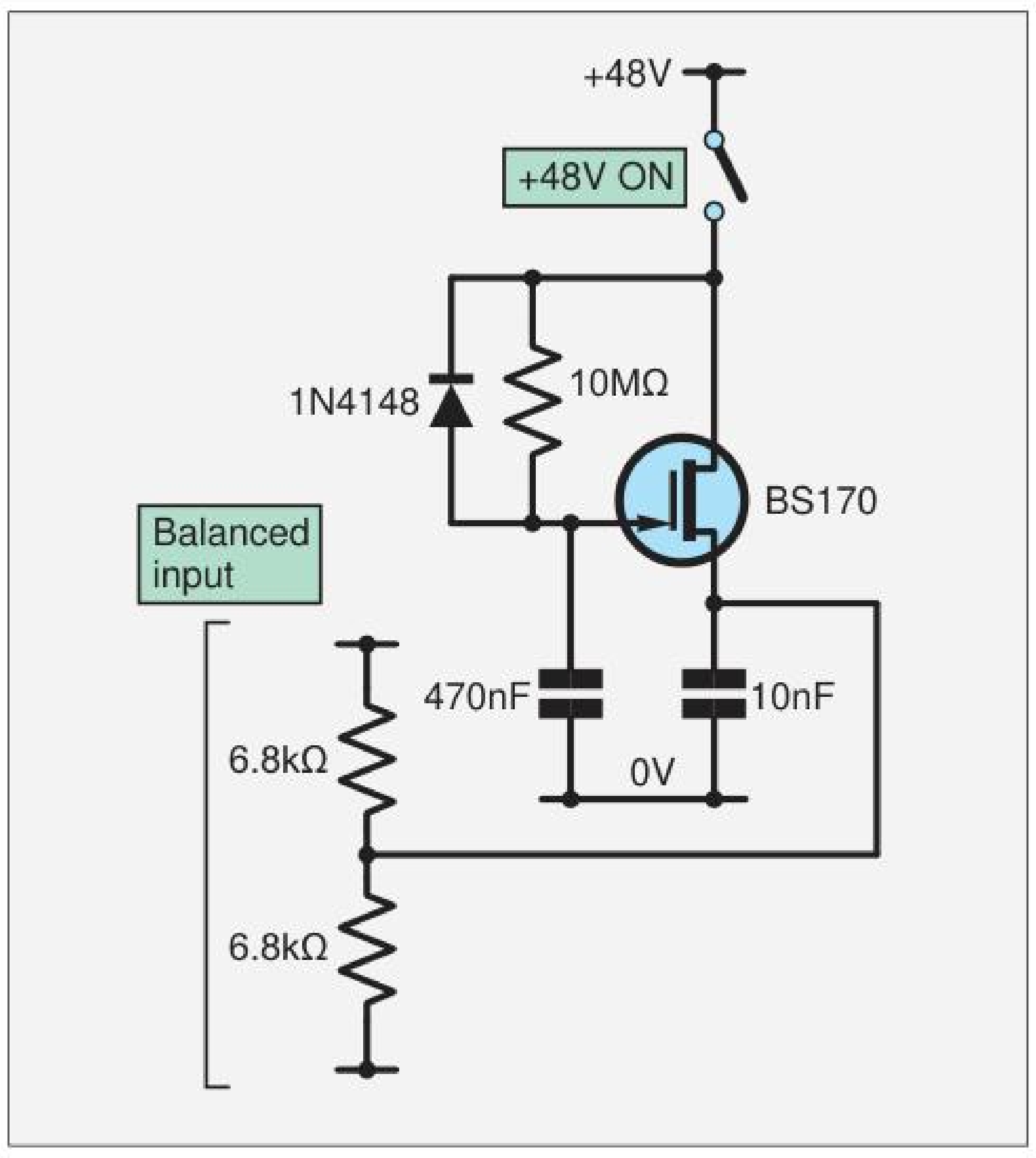


Fig.34. Switching on phantom power can produce ear-splitting cracks unless the rise time of the voltage is slowed. This can be done with a 100Ω resistor and 470µF capacitor or the capacitor multiplier circuit shown above.

Gain switch

Instrumentation-type amplifiers (as used in this design) use reverse-log-law gain control pots. Unfortunately, they are difficult to source. – but it gets worse! The 'standard' 15% C reverse-log-law pot give too abrupt a jump in gain at the limit of the rotation, and is therefore not optimal. A better law is the 8% RD law produced by Alps. (se Fig.35) That Corporation decided 2.5% was best, avoiding the sudden up-lift in gain. Such a pot would have to be specially made and be expensive. I should point out here that cermet and wire-wound pots have bad rotational noise, the wire-wound type sounds like undoing a zip! If you want to read up in more detail on potentiometer law details, then see my articles from *Audio Out*, November 2015 and April 2018.

The alternative to pots is switched gain, which enables each step to be optimised and allows the use of low-noise metal-film resistors. Cadac mixers use a 21-way switch and Neve preamplifiers often use multiway switches. The table opposite shows resistor values required for 2dB steps for the biggest 29-way switches available and Fig.36 shows its construction. If you have fewer steps, it's best to have the smallest increments on the highest gain settings.

That Corporation makes a special SMT chip for use with their 1570 microphone amplifier chip that includes electronic switching and a servo to control DC clicks, called the 5171. This has to be connected to a microcontroller, but it does give 1dB steps. Anyone fancy designing a rotary encoder circuit for it? Do note, however, that both chips are expensive (1570, £6 / 5171, £11 from Mouser). That said, I do worry about using single-sourced specialist chips, but anyone can make up a switch with a load of resistors on it.

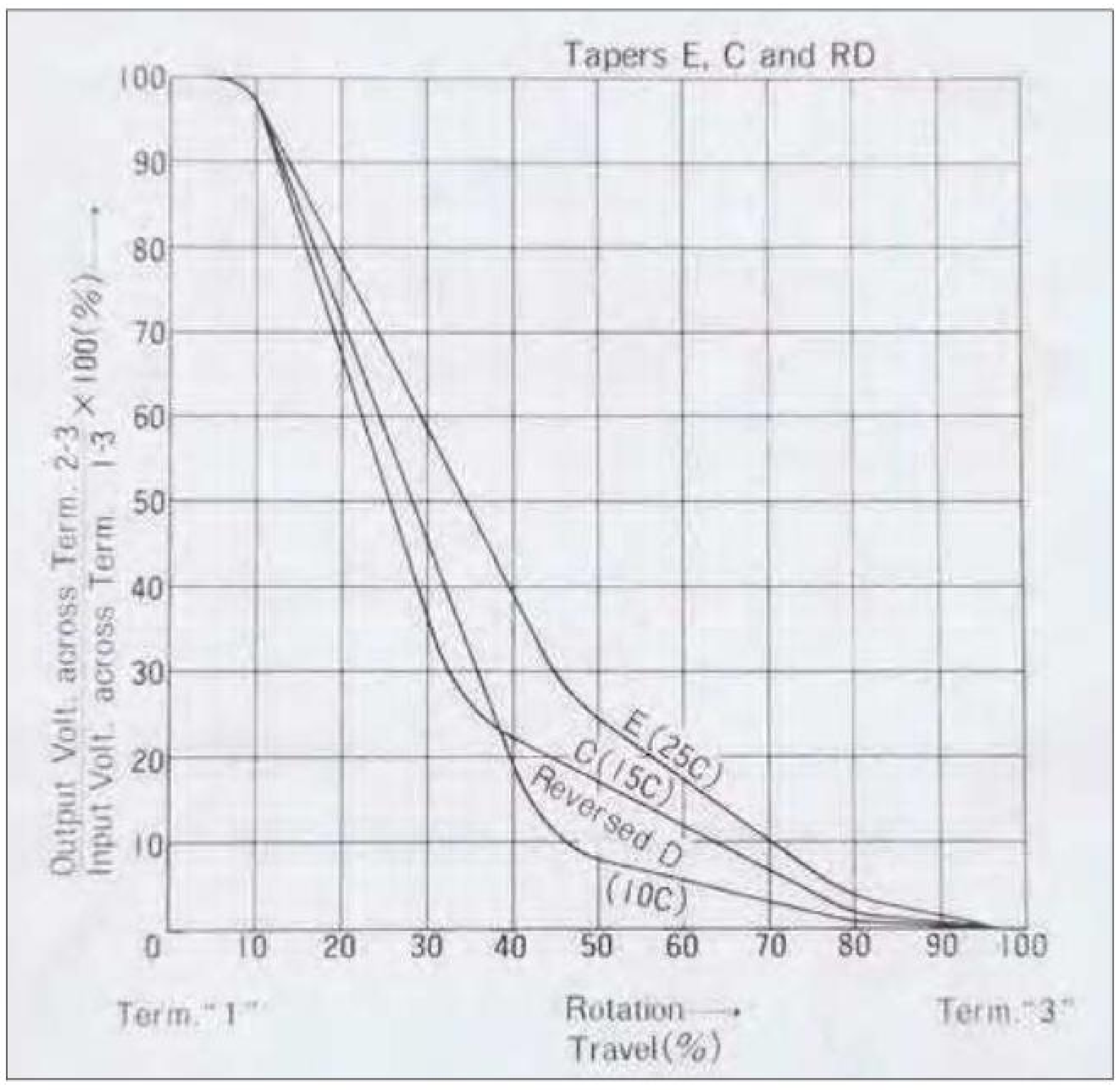


Fig.35. Alps reverse log pot tapers. This shows voltage/resistance vs rotation. At 50% rotation, a linear potentiometer split point would be would be 50% / 50%, taper C is 82% / 18% and RD is 92% / 8%.

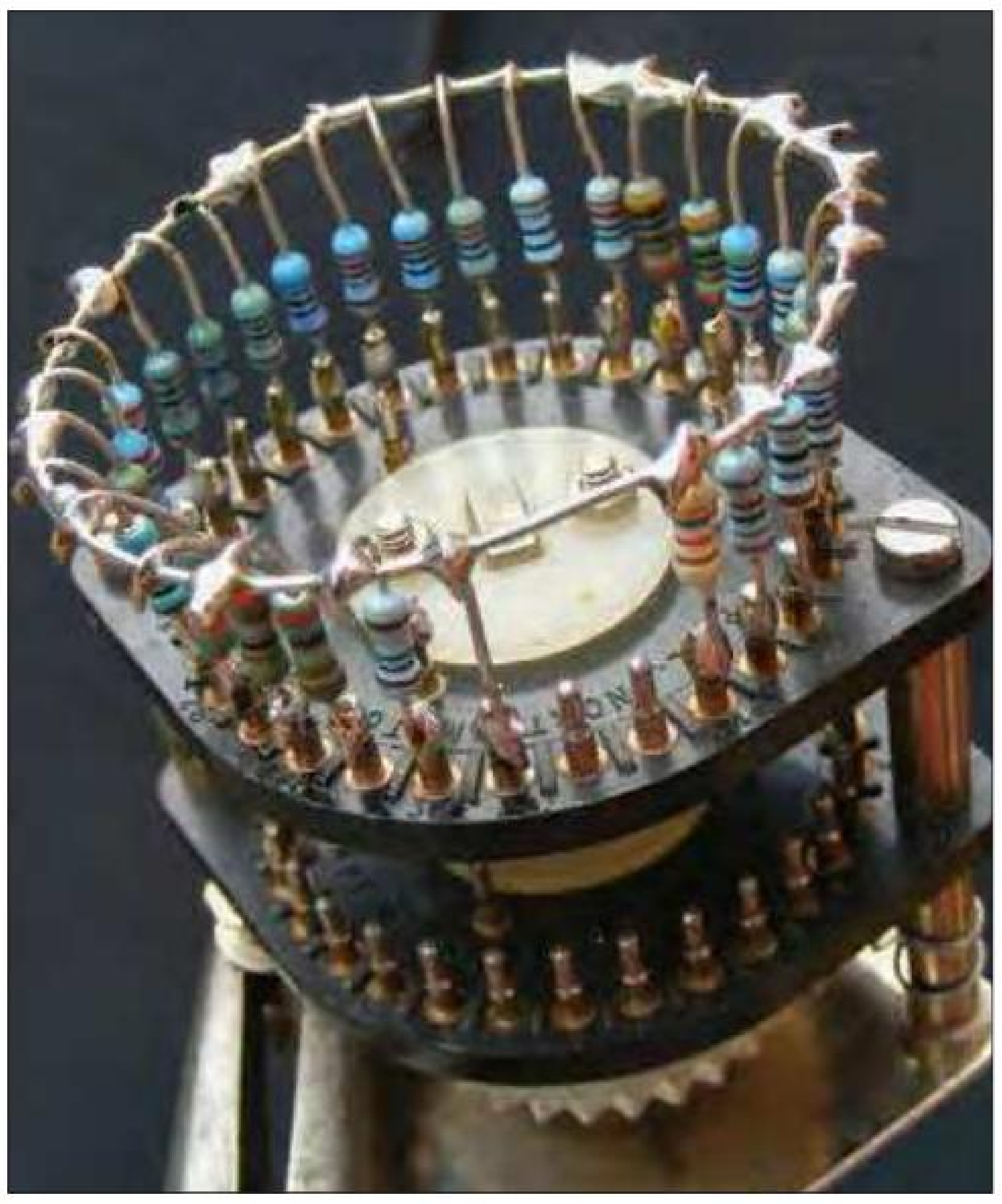


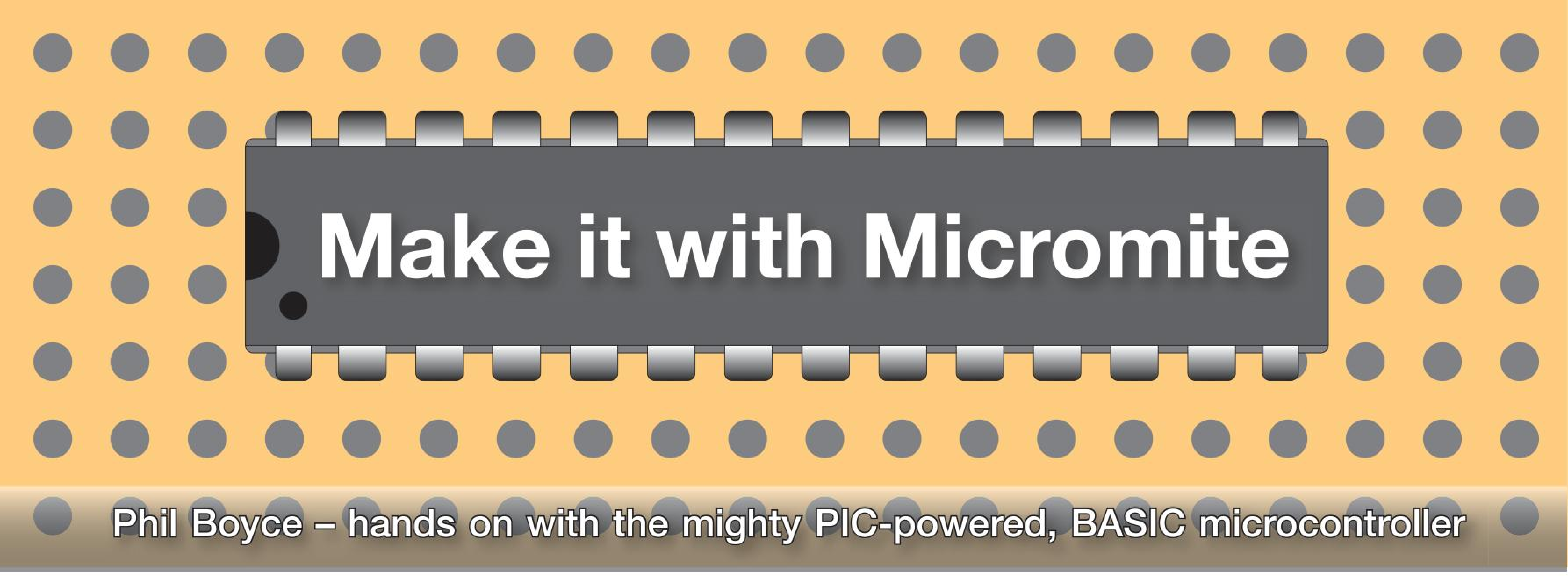
Fig.36. Test your soldering skills: a 29-way Painton switch with resistors attached, all different values. Note the ring of 22swg tinned copper wire that forms one terminal of the gain control; the other is the wiper. I often repurpose these high-quality specialist switches from old, scrapped test equipment.

Resistor values for stepped gain switch

Step	Gain (dB)	Ideal Resistance	E24 value
1	15	open	open
2	20	3.69kΩ	3.6kΩ
3	22	2.7kΩ	2.7kΩ
4	24	1.88kΩ	1.8kΩ
5	26	1.6kΩ	1.6kΩ
6	28	1.17kΩ	1.1kΩ
7	30	790Ω	750Ω
8	32	600Ω	620Ω
9	34	470Ω	470Ω
10	36	390Ω	390Ω
11	38	320Ω	300Ω
12	40	220Ω	220Ω
13	42	178Ω	180Ω
14	44	138Ω	130Ω
15	46	109Ω	110Ω
16	48	85Ω	82Ω
17	50	66Ω	68Ω
18	52	51Ω	51Ω
19	54	40.4Ω	39Ω
20	56	31.9Ω	30Ω
21	58	23.6Ω	24Ω
22	60	18Ω	18Ω
23	62	13.2Ω	13Ω
24	64	9.8Ω	10Ω
25	66	7.1Ω	6.8Ω
26	68	5.1Ω	5.1Ω
27	70	2.7Ω	2.7Ω
28	72	1Ω	1Ω
29	74	short	short

Next month

We'll conclude in *Part 4* with optional modifications, including the use of transformers.



Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 30: WeatherDemo explanation, and a PCB for the MKC

In this article we will conclude the topic of Wi-Fi internet connectivity for the Micromite by briefly explaining how last month's *WeatherDemo* program works. This really amounts to a discussion about two things: first, how to send a GET request to **openweather.org** (containing the location that you input when the program is run); and second, how the serial data is then extracted from the ESP32 module, which ultimately contains the weather data for the requested location.

We then proceed with a new idea that has come about following feedback from several *PE* readers. The underlying concept of the *Micromite Keyring Computer* (*MKC*) was always for it to be an easy DIY project that utilises just a handful of low-cost through-hole components; with these components simply being soldered onto a readily available piece of stripboard. This concept was also applied to subsequent hardware add-ons, such as the *Development Module* (*DM*), for example.

However, even though the topics and projects covered in this series have been very well received, some readers have highlighted that it is rather a time-consuming process to prepare the required stripboard (ie, having to cut out the correct size and shape, then making the track-cuts in all the correct positions, and then having to solder any required wire-links into place).

The best way to remove the need for preparing a piece of stripboard is to simply offer an alternative construction route with a PCB. So, this month we introduce the *MKC* PCB, the first in a planned set for the *Make it with Micromite* series.

WeatherDemo

Now, back to explaining how last month's *WeatherDemo* program works. Fully appreciating that you are reading an electronics magazine rather than a coding magazine, we will once again limit this to discussing the building block steps used rather than going into the full details behind each and every command and line of code used. Remember that the *Micromite User Manual* can be referred to for an explanation of any MMBASIC command used in the program. Likewise, the use, and structure, of each AT Command used is detailed on the ESP manufacturer's website (**http://bit.ly/pe-may21-exp**). In addition, there is more information about any request parameter options on the **openweathermap.org** website (API documentation).

Sending a GET request

Last month, we discussed how to sign up for an **openweathermap.org** account in order to get an API key. We also showed you how to test your unique API key by typing the following request into a web-browser (replacing the `XXXXXX` with your API key):

```
api.openweathermap.org/data/2.5/
  weather?q=London,uk&APPID=XXXXXX
```

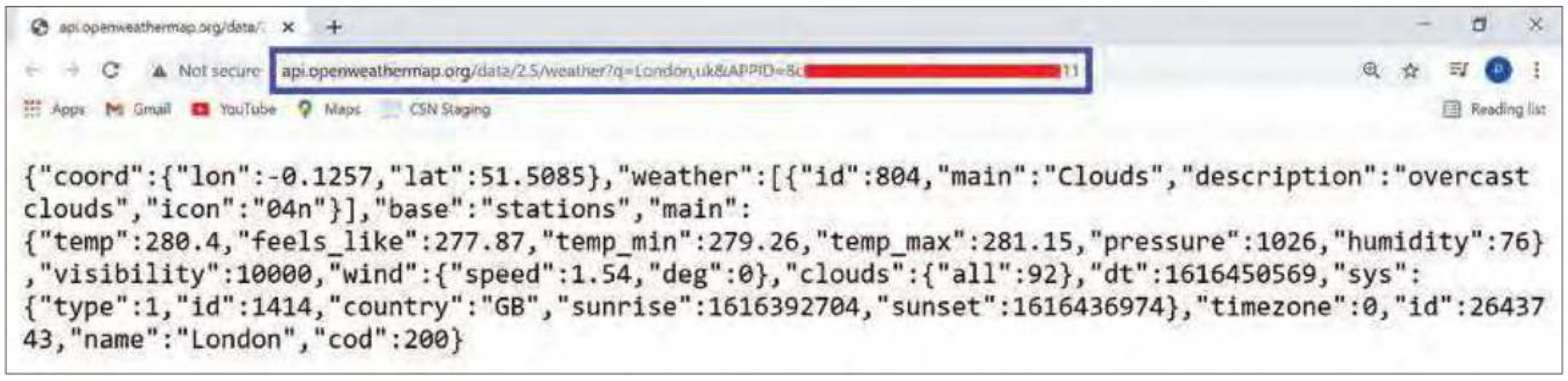
This effectively sends a request to **openweathermap.org** for some data, with any parameters (ie, location and API key) being part of the request (here, `?q=London,uk` and `&APPID=XXXXXX`). Once this request has been processed by their server, a response is sent back to your browser. Their response is in the JavaScript Object Notation (more commonly known as a JSON response) and your browser is able to display the returned data in the format shown in Fig.1.

Note that the above method uses a computer's browser, but of course we're using an ESP32 module and a Micromite instead. So ideally we need a simple Micromite way to somehow send the above request. Without going into too much detail, your browser is actually sending a GET request to **openweathermap.org** and this is something the ESP32 can easily handle.

To be more specific, a TCP connection is first made by the ESP32 module to the **openweathermap.org** server, and once a connection is made, an HTTP GET request is then sent. The ESP32 then receives an HTTP response from the **openweathermap.org** servers (in JSON format), and finally the TCP connection is closed.

AT+CIPSTART

Fortunately, the ESP32 has an AT command that makes it easy to establish the required TCP connection. The command's format is:



api.openweathermap.org/data/
Not secure
api.openweathermap.org/data/2.5/weather?q=London,uk&APPID=8c[redacted]11
Apps
Gmail
YouTube
Maps
CSN Staging
Reading list

```
{"coord":{"lon":-0.1257,"lat":51.5085},"weather":[{"id":804,"main":"Clouds","description":"overcast
clouds","icon":"04n"}],"base":"stations","main":
{"temp":280.4,"feels_like":277.87,"temp_min":279.26,"temp_max":281.15,"pressure":1026,"humidity":76}
,"visibility":10000,"wind":{"speed":1.54,"deg":0},"clouds":{"all":92},"dt":1616450569,"sys":
{"type":1,"id":1414,"country":"GB","sunrise":1616392704,"sunset":1616436974},"timezone":0,"id":26437
43,"name":"London","cod":200}
```

Fig.1. You can use a web browser and your API key to get the weather data for any location (see text). Shown here is weather data for London.

```
AT+CIPSTART="TCP","host",port_number
```

where *`host`* needs to be set in our example to *`openweathermap.org`* (or the equivalent IP address), and *`port_number`* needs to be set to *`80`*. We are sending this AT command with the `SendAT` subroutine discussed last month, so we will need to load it into `AT_CMD$` as a string. However, MMBASIC needs to send each double quote character within a string as `CHR$(34)`, and hence `AT_CMD$` needs to be set as follows:

```
AT_CMD$="AT+CIPSTART="+Chr$(34)+"TCP"+Chr$(34)+","
  +Chr$(34)+"api.openweathermap.org"+Chr$(34)+",80"
```

This may seem a little confusing at first glance, but just remember that an MMBASIC string needs to be surrounded by double quotes, and multiple strings can be joined together with the + character.

When the `AT_CIPSTART` command is sent to the ESP32 module (by calling the `SendAT` subroutine), an attempt to establish a TCP connection is made. Assuming the ESP32 module is connected to a Wi-Fi network with Internet access, and also assuming the remote server at **openweathermap.org** exists (and is up and running), then a TCP connection will be established. This will result in the ESP32 sending back a `"CONNECT"` and an `"OK"` to the Micromite. You can refer to the ESP user manual for more details on this command.

AT+CIPSEND

Once a TCP connection is established with a remote server, the command `AT+CIPSEND` needs to be sent. This will cause the ESP32 to respond with an `"OK"` and `">"` (or with `"ERROR"` should anything be wrong). This command puts the ESP32 module into what is called *data sending* mode, which means that any characters now sent to the ESP32 (from the Micromite) will be sent to the remote server that the ESP32 is currently connected to. Thus, we can now send our GET request (see next section). Note that to terminate the data sending mode, three consecutive + characters need to be sent. On sending `"+++"`, and providing the data was successfully sent to the server, the ESP32 will respond with `"SEND OK"`.

The GET request

In our *WeatherDemo* program code, we simply load the required GET request into the string `WWcmd$`, and then use `PRINT #1` to send it to the ESP32 module. Let's take a closer look at the exact format of the GET request.

Above, we gave an example of what needs to be typed into a browser; repeating it here, the format of the request is:

```
api.openweathermap.org/data/2.5/weather
  ?q=London,uk&APPID=XXXXXX
```

This can be viewed as comprising two parts:

```
api.openweathermap.org
  and
/data/2.5/weather?q=London,uk&APPID=XXXXXX
```

What we do with the ESP32, however, is slightly different, bearing in mind that we already have a connection to the **api.openweathermap.org** server (ie, the first part of the request above) which was established by using the command `AT+CIPSTART…`

So, we just need to send the second part – but this needs to be formatted correctly into the following three lines:

line 1 `GET` *`followed by the second part above`* `(carriage-return / line-feed)`
line 2 `HTTP/1.0 (carriage-return / line-feed)`
line 3 `(carriage-return / line-feed)`

If you refer to the program code, you should now understand how the above is being stored into the string `WWcmd$` with:

```
WWcmd$="GET /data/2.5/weather?q="+Place$+
  "&units=metric&appid="+APIKEY$
WWcmd$=WWcmd$+Chr$(13)+Chr$(10)+"HTTP/1.0"+
  Chr$(13)+Chr$(10)+Chr$(13)+Chr$(10)
```

There are three things to point out here:

1. The location of `London` (in the browser example) is replaced with the string `Place$`. This string contains whatever location you type in when the program is run, making it much more flexible.
2. There is a `units` parameter that has been set to `metric`. This simply returns any temperature values in centigrade. If you would like to experiment further with other parameters, you should refer to the API documentation available on the **openweathermap.org** website. This provides full detail of all the available parameters and their permitted values. Just add them into the `WWcmd$` string, each one starting with an `&` symbol as shown above.
3. `Chr$(13)+Chr$(10)` is the equivalent of a carriage return / line feed (often shortened to CrLf or CR/LF)

Referring to the program code, after the correctly formatted GET request has been sent (with `PRINT #1,WWcmd$`), you can see that the code calls the `GetData` subroutine which waits for any response back from the remote server. It will wait up to a maximum of 1.8 seconds (ie, 1800ms) which is set by loading the value `1800` into variable `AT_TimeOut`.

Extracting the data

The `GetData` subroutine is called so that our program code can wait for any data received from the remote server. What should be received is effectively what you see in Fig.1. In other words, lots of data separated by colons, commas, and various brackets. As mentioned last month, if you look at the data closely, you will see that it generally follows the format: *`"parameter name":"parameter value"`*.

The `GetData` subroutine simply breaks all this data down into individual lines for displaying on the screen. It also checks to see if it receives either `"cod":"200"` (success) or `"cod":"400"` (error). If so, it means that there is no more data to be received, so it simply exits the `GetData` subroutine. At this point, the code can send `"+++"` to exit the *data sending* mode, and then it can close the TCP connection to the remote server by sending the command `AT+CIPCLOSE`.

The program then loops back to request a new location input, and once entered, the whole process is repeated; ie, establish a TCP connection to the remote server, send a GET request, wait a brief while for the server response, display any response, and finally close the connection to the remote server.

Fancy a challenge?

This example has provided you with enough detail for you to experiment with connecting to other services that are available via the Internet. As always, the best way to learn is to simply experiment by yourself (and use Google if you need to – there is so much online information available). Remember that all we have used for this Wi-Fi topic is just a single low-cost ESP32 module, and four jumper wires (0V, 3.3V, Tx, and Rx) to connect the ESP32 to the Micromite. Everything else is then determined by software.

So why not challenge yourself to try to connect your Micromite to some other servers. Perhaps see if you can get a listing of what is on television; or maybe try and get the prices of goods from an online retailer. For the really adventurous, try using POST (instead of GET) to send data to a remote server!

The MKC PCB

Back in the February 2019 issue we began the *Make it with Micromite* series, introducing the *Micromite Keyring Computer* (*MKC*); and in *Part 2*, we worked through the *MKC* hardware assembly. The circuit diagram of the *MKC* is repeated below in Fig.2, and the assembled stripboard is shown in Fig.3. Following some useful reader feedback, we decided to create a PCB for this circuit, which is shown in Fig.4. The *MKC* PCB is the same size and shape as the original stripboard design; and all the connectors have been placed in identical positions. Naturally, the electronics remains the same as before. Hence, this PCB is a nice alternative to using the stripboard. Assembly is very straightforward, but there are a few things we wish to point out.

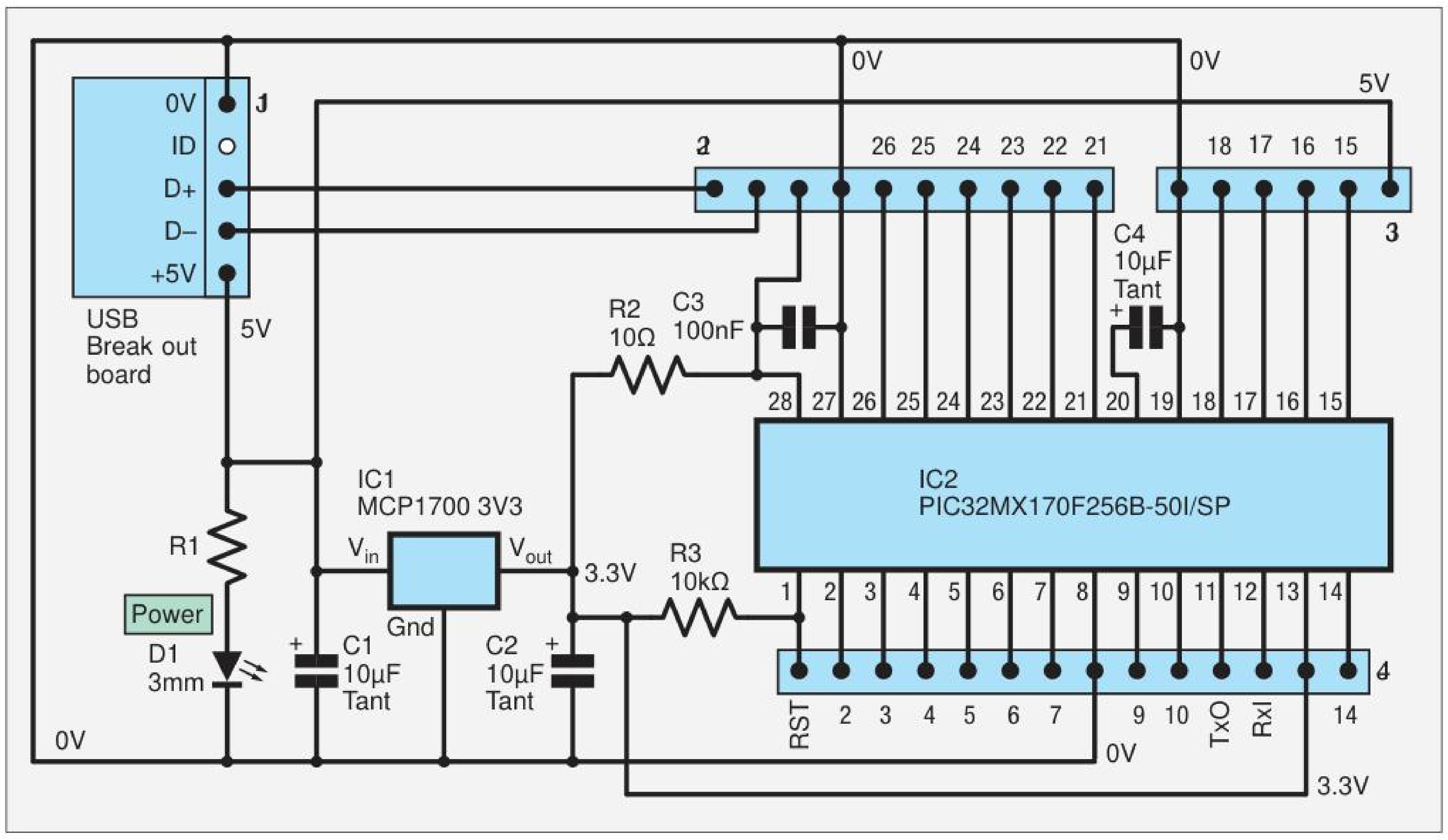

0V
ID
D+
D–
+5V
USB Break out board
5V
R1
Power
D1 3mm
0V
IC1 MCP1700 3V3
Vin
Vout
Gnd
C1 10µF Tant
C2 10µF Tant
3.3V
R2 10Ω
C3 100nF
R3 10kΩ
IC2 PIC32MX170F256B-50I/SP
C4 10µF Tant
0V
0V
5V
1
2
3
4
26 25 24 23 22 21
18 17 16 15
28 27 26 25 24 23 22 21 20 19 18 17 16 15
1 2 3 4 5 6 7 8 9 10 11 12 13 14
RST 2 3 4 5 6 7 9 10 TxO RxI 14
0V
3.3V

Fig.2. Circuit diagram for the *Micromite Keyring Computer* (*MKC*).

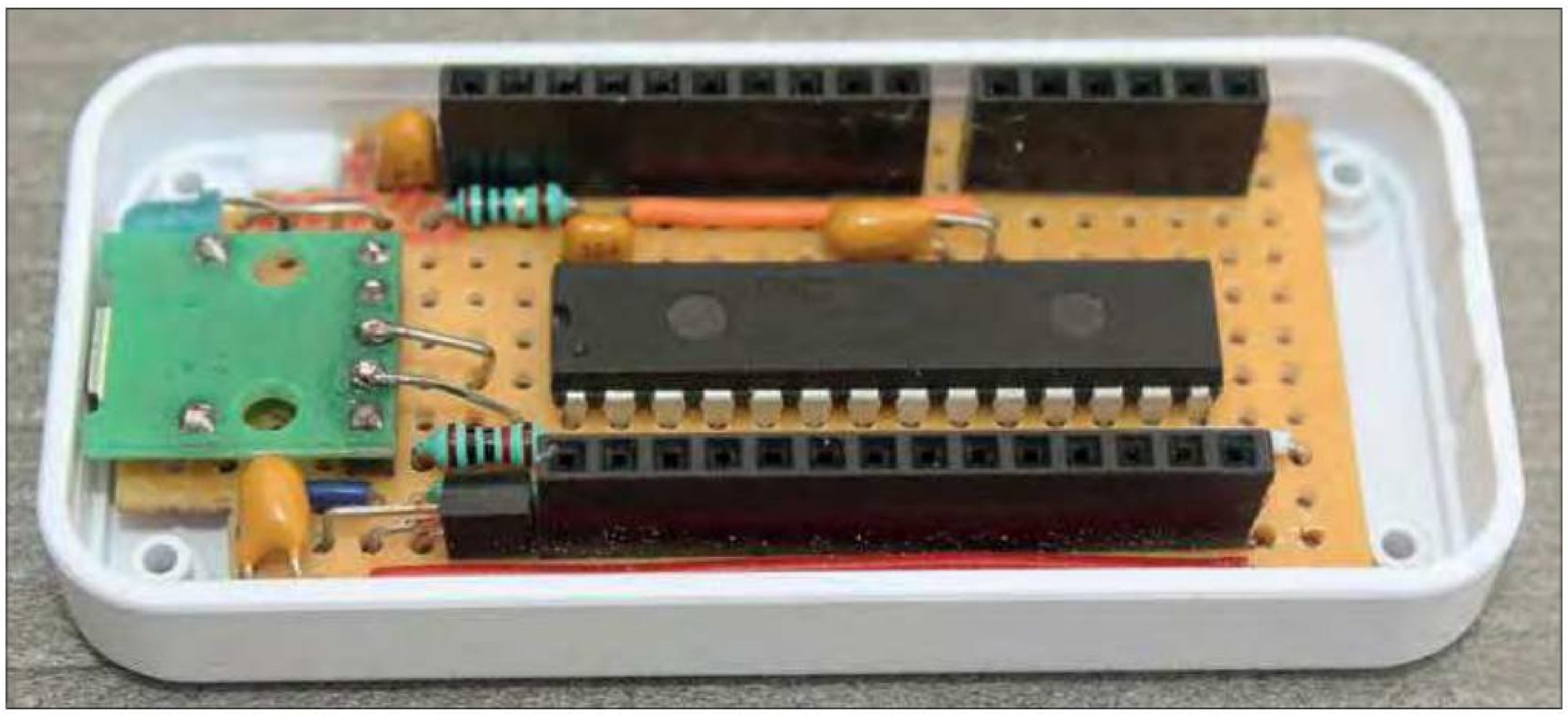


Fig.3. The assembled *MKC* stripboard in the bottom part of the recommended enclosure.

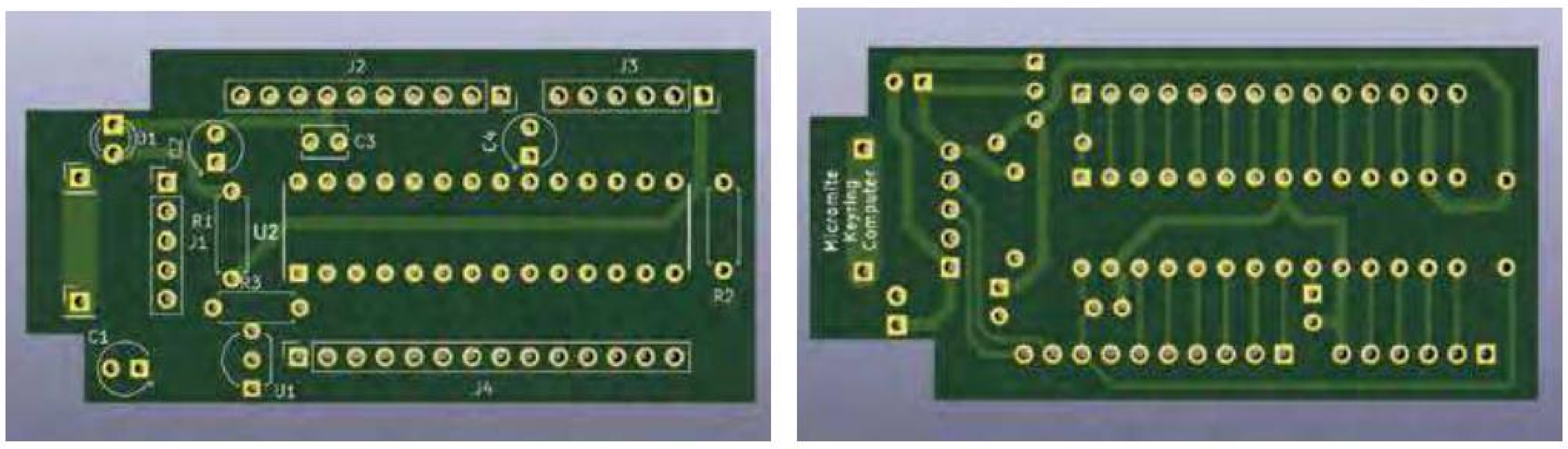

J2
J3
D1
C3
U2
R1
J1
R3
R2
C1
U1
J4
Micromite Keyring Computer

Fig.4. Rendered views of the *MKC* PCB: (left) component side, (right) underside.

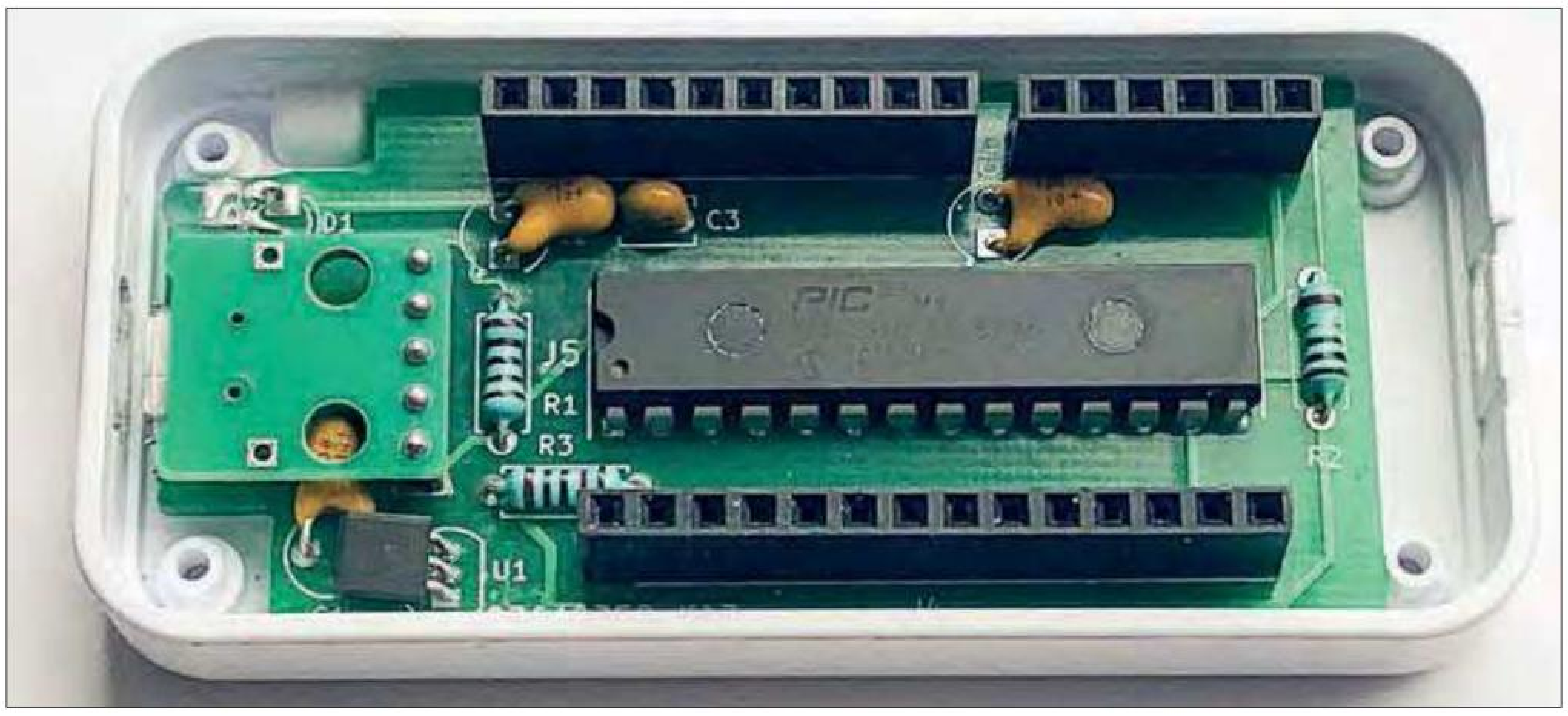

D1
C3
J5
R1
R3
U1
R2

Fig.5. The assembled *MKC* PCB mounted in the bottom part of the keyring enclosure. Note that the *MKC* PCB shown here is an early prototype.

PCB assembly

The silkscreen on the PCB follows the component labelling shown in the circuit diagram in Fig.2 (apart from IC1 and IC2 which are labelled 'U1' and 'U2'). Note that the positions of some components have been slightly changed to improve the overall assembly process. For example, R1 has been moved from under the USB Break-out-Board (BoB), and the voltage regulator and LED no longer require their leads to be bent in an odd way; minor but worthwhile improvements.

The three 10µF tantalum capacitors are polarised, as is the LED, so care needs to be taken with these to ensure they are installed the correct way round. The PCB has '+' markings on the silkscreen to assist with this. Otherwise, everything is as before. We still solder the 28-pin Micromite chip directly into place (ie, no DIL socket), as this allows the enclosure's top to be fitted correctly. If you are not going to mount the *MKC* in the recommended enclosure, then we suggest using a DIL socket. Once the PCB is assembled and mounted in the bottom part of the enclosure, it should look like Fig.5.

When the top of the enclosure has been attached, your *MKC* is ready for use in exactly the same way as the original version.

Do look out for upcoming articles for the other PCBs from the *Make it with Micromite* series. We will be creating one for the *Development Module* (*DM*) very soon. Simply contact **micromite.org** if you would like an *MKC* PCB, or a PCB version of the *MKC* kit.

Next month

Inspired by the IoT Cricket module that was introduced in last month's *Practical Electronics*, in the next *Make it with Micromite* we will show you just how easy it is to connect a Micromite to a Cricket so that MMBASIC can trigger data to be sent to the internet. Until then, have FUN!

Questions? Please email Phil at:
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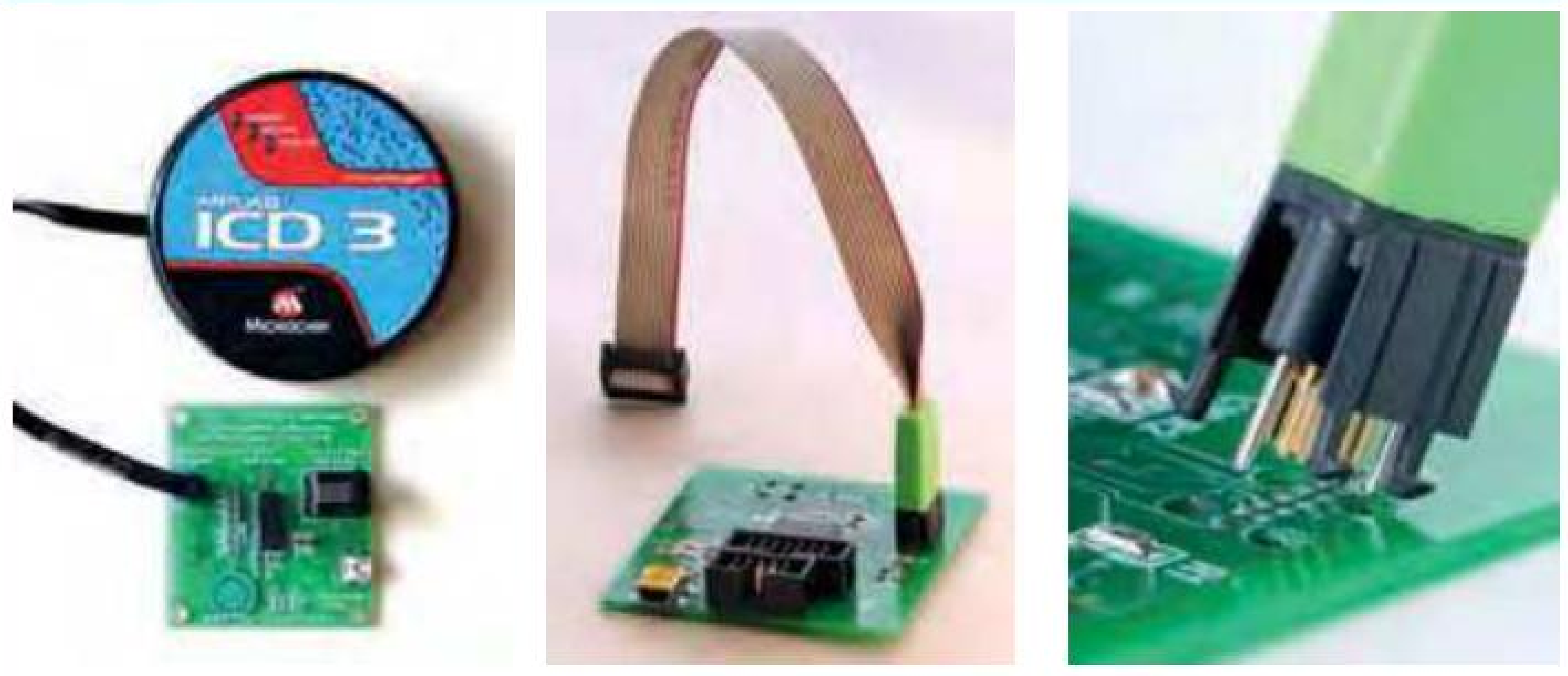

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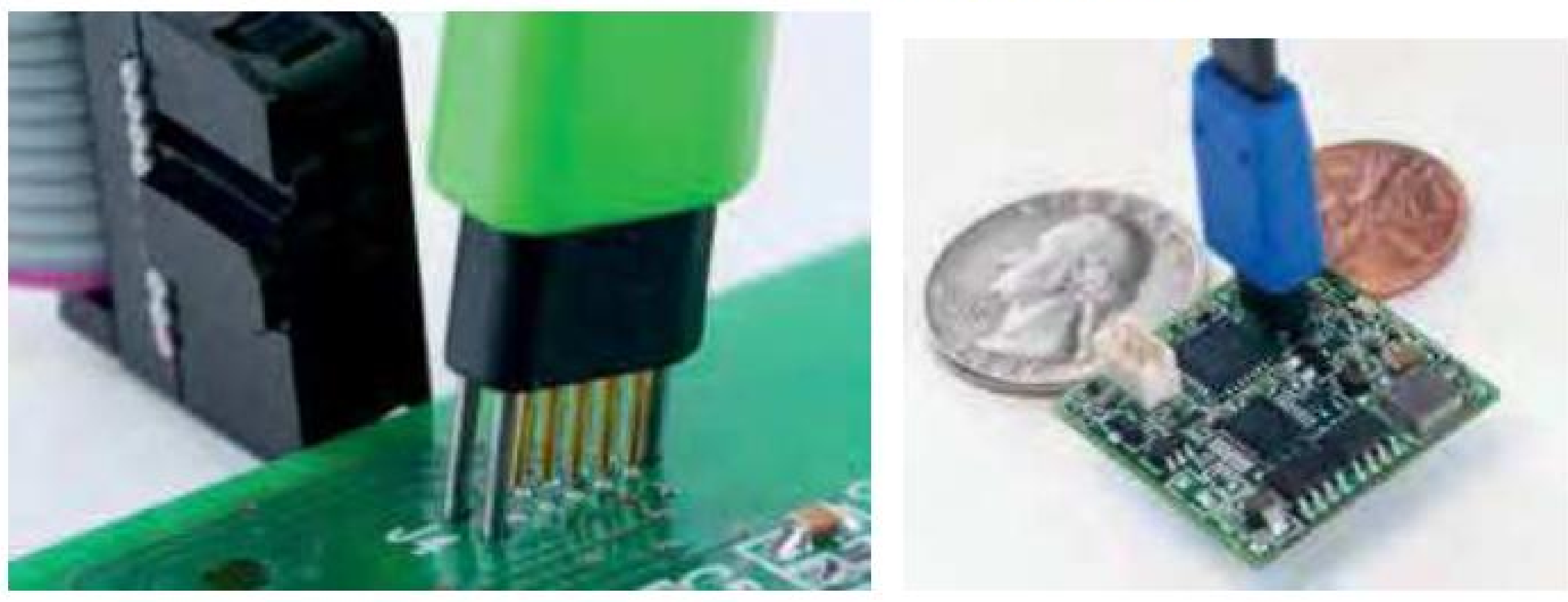

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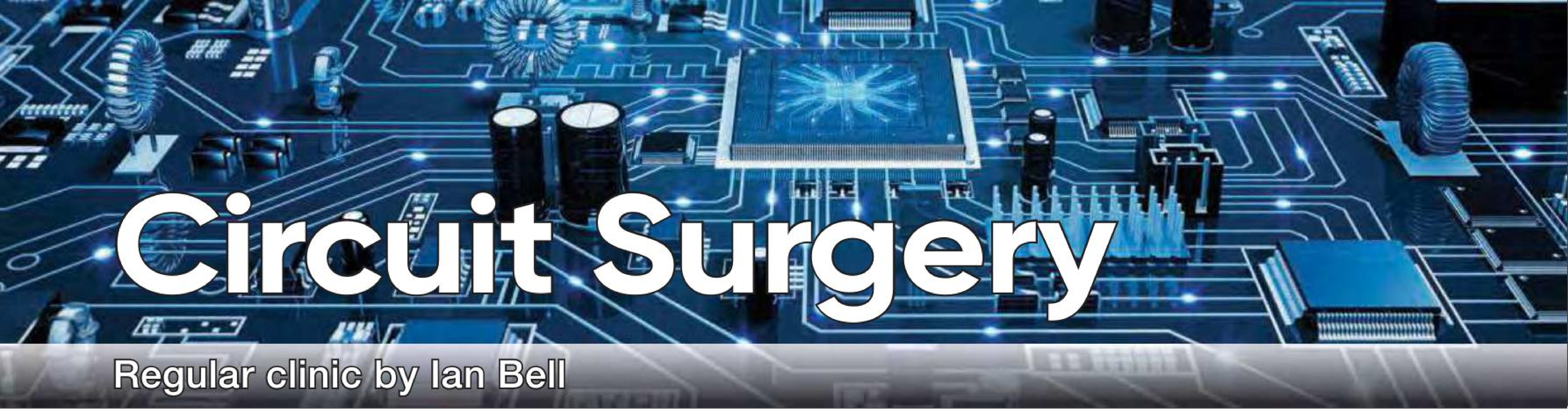

Circuit Surgery

Regular clinic by Ian Bell

Transformers and LTspice – Part 2

We continue from last month looking at the basics of transformers and some aspects of simulating transformer circuits in LTspice. We will start with a quick recap and then look at transformers with multiple secondaries. Then we will look at how transformers are used with rectifier diodes to obtain low-voltage DC from mains inputs.

Transformer review

We explained last month that a transformer comprises two or more coils or windings (looped conductors) in close physical proximity which provide the capability to transfer electrical energy, in the form of alternating current, from one circuit to another without an electrically conductive connection being required. Key properties of transformers are that they provide electrical isolation between circuits, they can change voltage levels and they change the effective impedance of a load connected via a transformer rather than connected directly.

The relationship between the voltages and currents in a transformer depends on the ratio of turns between the input (primary) and output (secondary) windings. The secondary voltage is equal to the primary voltage multiplied by the secondary/primary turns ratio. The secondary current is divided by the same ratio. Depending on the ratio, the secondary voltage may be stepped up (with lower current than at the primary) or stepped down (with higher current). The power input and output are equal for an ideal transformer, but real devices have losses and do not achieve 100% power transfer. The nature of these losses is complex (eg, amount of flux coupling, properties of core materials and structure), so, although the basic principle of the transformer as a circuit component is straightforward, very accurate and detailed design, analysis and simulation of transformer circuits can be challenging.

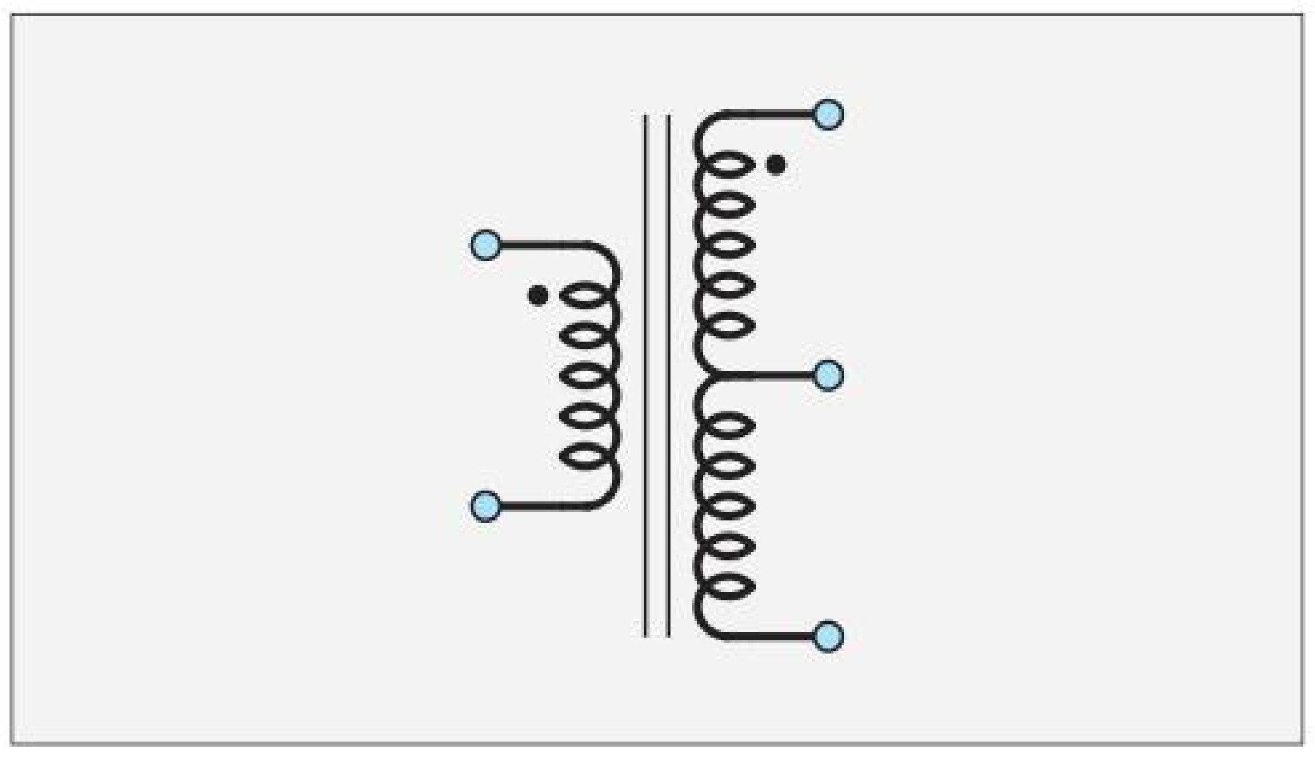

Fig.1. Symbol of transformer with centre-tapped secondary.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*. The examples and files are available for download from the *PE* website.

Last month, we also looked at some basic transformer simulations in LTspice. Transformers are perhaps the trickiest of the basic passive components to use in SPICE – there is no transformer element – you have to create one from multiple inductors and use a mutual inductor element to link them together. The mutual inductor has to be placed on LTspice as a text SPICE element (eg, `K1 L1 L2 1` to link inductors `L1` and `L2` with an ideal coupling coefficient of `1`). The inductor values are set so that the square root of their ratio, $\sqrt{(L_p/L_s)}$ is equal to the turns ratio. The actual inductance value can be obtained from device data, measured, or estimated so that it is consistent with the operating current at the frequency used.

Multiple windings

So far, we've only looked at transformers with one primary and one secondary. Multiple secondaries are common, and some transformers have multiple primaries; typically so they are adaptable to use over a range of conditions by choosing which primary to use – although great care has to be taken with this, particularly for higher voltages, such as mains. As always, the manufacturer's data must be consulted. It is common for two primaries or secondaries to be wired together as part of the transformer construction, rather than being completely separate. This is referred to as a 'centre tapped winding' and the middle connection is the centre tap. Of course, taps do not have to be half-way and some transformers have multiple taps. The symbol of a transformer with a centre-tapped secondary is shown in Fig.1.

Multiple independent secondaries can be used separately or connected in series to combine the secondary voltages. If they are connected, then the phase of the connections must be taken into consideration – in-phase voltages add, while out-of-phase voltages subtract. Parallel connection of secondaries may also be possible, but *only* if the voltages are equal *and* the transformer has been specified as being suitable for this kind of configuration. Even a small voltage difference can cause damagingly high currents to flow in secondaries with low winding resistance.

Fig.2 shows an example of a transformer with two secondaries in LTspice. Remember that the inductors on their own (here, `L1`, `L2` and `L3`) do not create a transformer, whichever way they happen to be drawn on the schematic. Also, the core lines between the windings are created with the draw function and are purely graphical – they have no effect on the simulation. As previously mentioned, the mutual inductor (`K1` element) links the inductors to form the transformer. To keep things

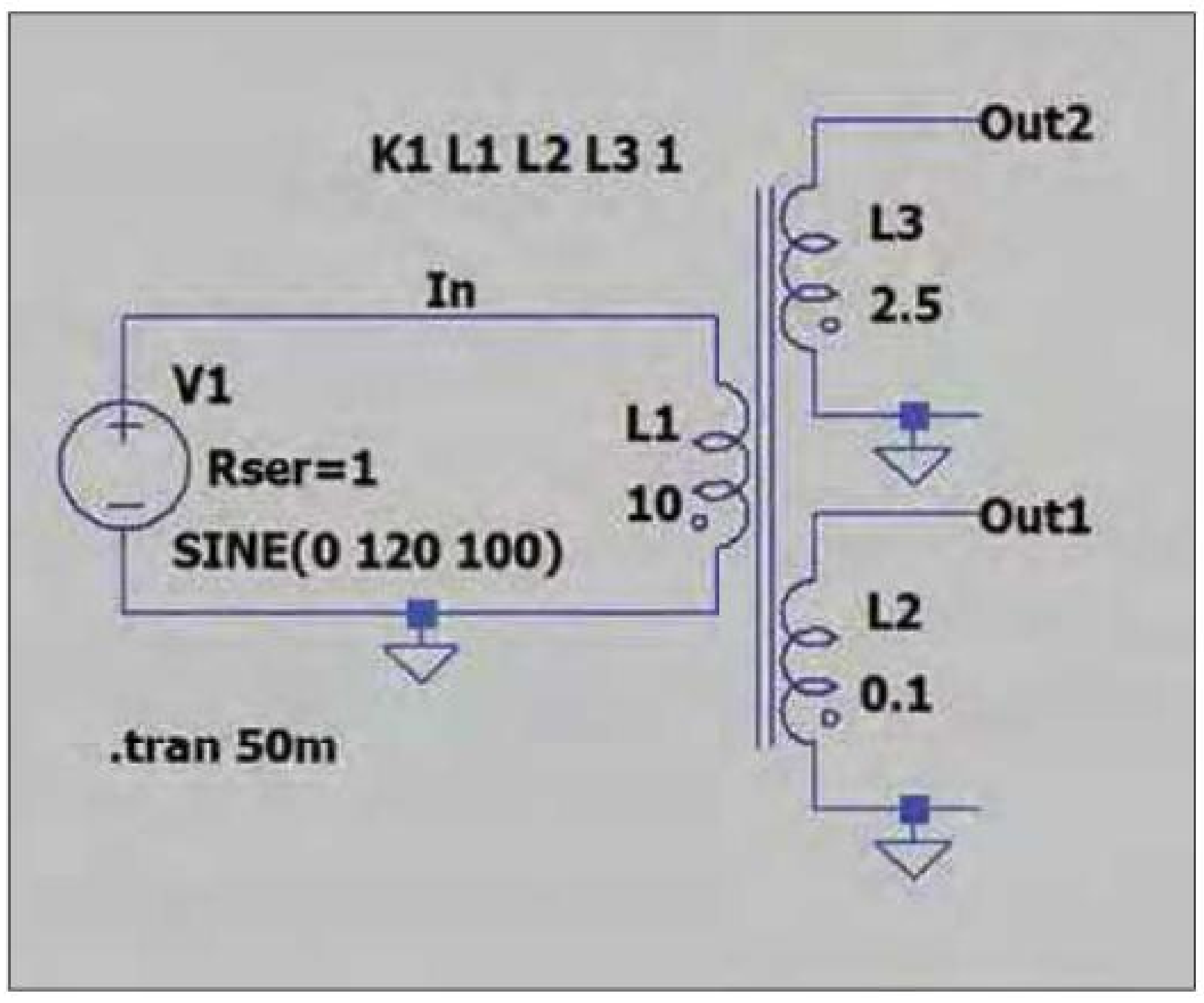

Fig.2. LTspice schematic of a transformer with two secondaries.

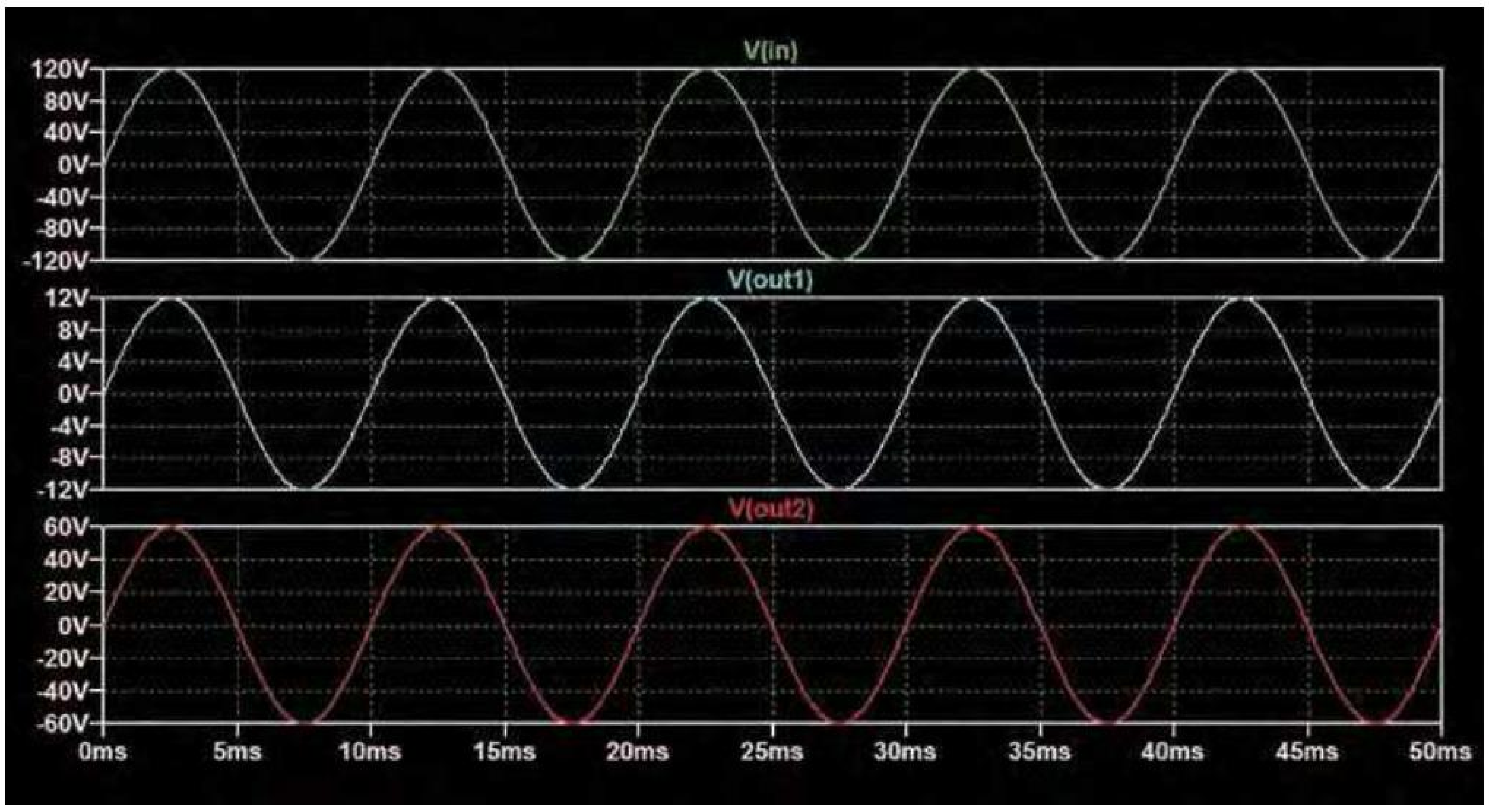

Fig.3. Simulation results for the circuit in Fig.2.

simple, a coupling coefficient of `1` is used. The turns, and hence voltage ratio is equal to the square root of the inductance ratio. In this example, the inductance ratio from the primary (`L1`) to secondary (`L2`) is 10:0.1 or 100:1, therefore the voltage (turns) ratio is the square root of this (10:1), so with the 120V input shown `Out1` will be 12V. Similarly, `Out2` (from secondary `L3`)will be 60V (10:2.5 = 4:1 inductance ratio, 2:1 voltage and turns ratio). Fig.3 shows the simulation results for the circuit in Fig.2 – the voltages are as calculated. All the waveforms are in phase because all the windings are in phase – in this case with the ‘phase dot’ end of the windings grounded in each case.

Fig.4 shows an LTspice schematic with two copies of the transformer from Fig.2. One circuit has the secondaries connected in phase (with output `OutA`) and the other has them out of phase (with output `OutS`). The voltages from the two windings add in the first case – `OutA` is 60 + 12 = 72V and they subtract in the second case – `OutS` is 60 – 12 = 48V. The phase dots on the schematic show the phase of each winding. The simulation results for the circuit in Fig.4 are shown in Fig.5, confirming the voltages just calculated. `OutS` is out of phase with `OutA` because the 60V winding is connected in opposite phase to the wiring for `OutA`. Subtracting voltages is an important aspect of transformer theory, but is not likely to be used much in real circuits – it is better to choose a transformer with a winding that directly provides the required output. Adding voltages occurs in centre-tapped and multi-tapped windings (or separate winding connected this way).

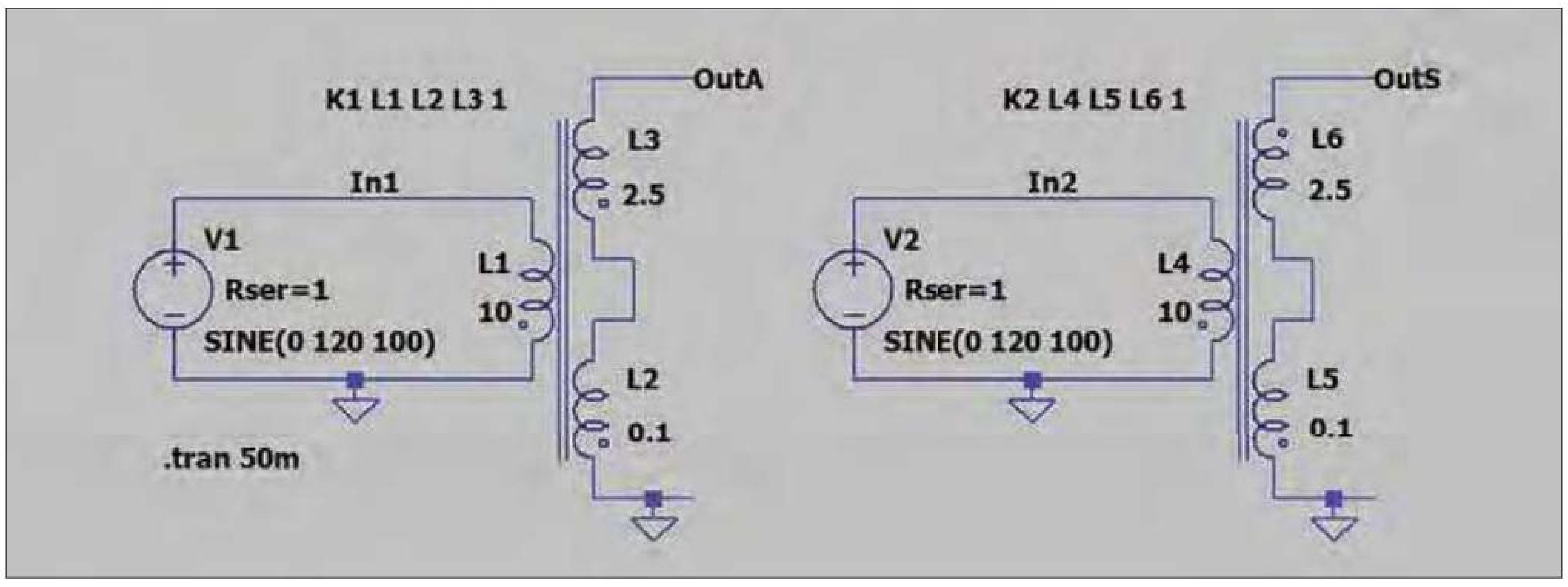

Fig.4. Examples of secondaries connected together – note the phase dots. The windings are in phase for `OutA` and out of phase for `OutS`.

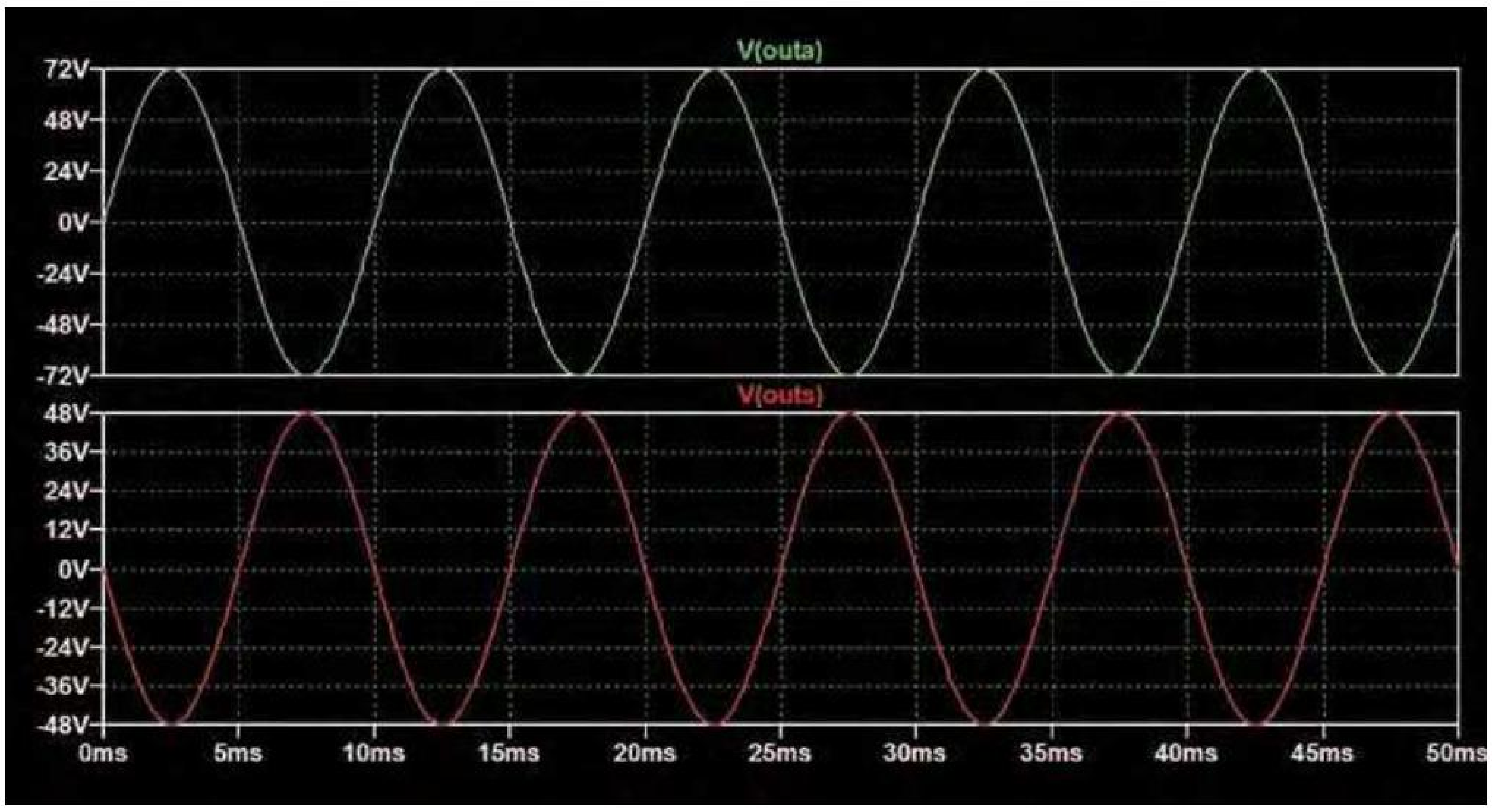

Fig.5. Simulation results for the circuit in Fig.4.

Transformers for power supplies

Transformers are widely used directly to step down mains voltages to lower voltages for use by electronic circuits – however, there they are less common than they used to be because direct-off-line switch-mode power supplies (SMPS) provide advantages of better efficiency and reduced size, weight and cost. SMPS may still use transformers, but they switch at much higher frequencies than the mains, facilitating the use of much smaller transformers (or just an inductor). However, mains frequency transformers with linear regulators may be better in some situations – particularly if you cannot avoid the SMPS switching noise being in the same frequency range as the signals being processed.

Fig.6 shows the first part of a typical mains power supply circuit – the transformer and a bridge rectifier. In a power supply this would normally be connected to a smoothing capacitor and voltage regulator, but we are not looking at a full power supply circuits here – just the ways the transformer is used

The voltage source `V1` represents the mains. The voltage is 325V to correspond with the (peak) UK mains. The voltage normally quoted for the mains is the RMS (root mean square) voltage, which in the UK is the more familiar 230V. The 230V value is equal to the DC voltage which would cause the same power dissipation in a resistor as the AC signal. However, we are required to specify the peak voltage for a sinewave source in SPICE. The peak voltage of an AC signal is larger than the RMS value, specifically, for a pure sinewave, the peak voltage is $\sqrt{2}$ (1.4142) times the RMS value (for UK mains, $230\text{V}_{RMS} \times 1.4142 = 325.3\text{V}_{peak}$). The turns ratio of a transformer can be used on either the RMS or peak voltage. For example, a turns ratio of 10:1 will give 23V_{RMS} out for 230V_{RMS} in, or 32.5V_{peak} out for 325V_{peak} in.

The transformer in the circuit is configured to produce 12V_{peak} at the secondary – a voltage (turns) ratio of 325:12 = 27.08:1 requires an inductance ratio of 733.5:1. A ratio of 10:0.01363 is used here so that the primary (at

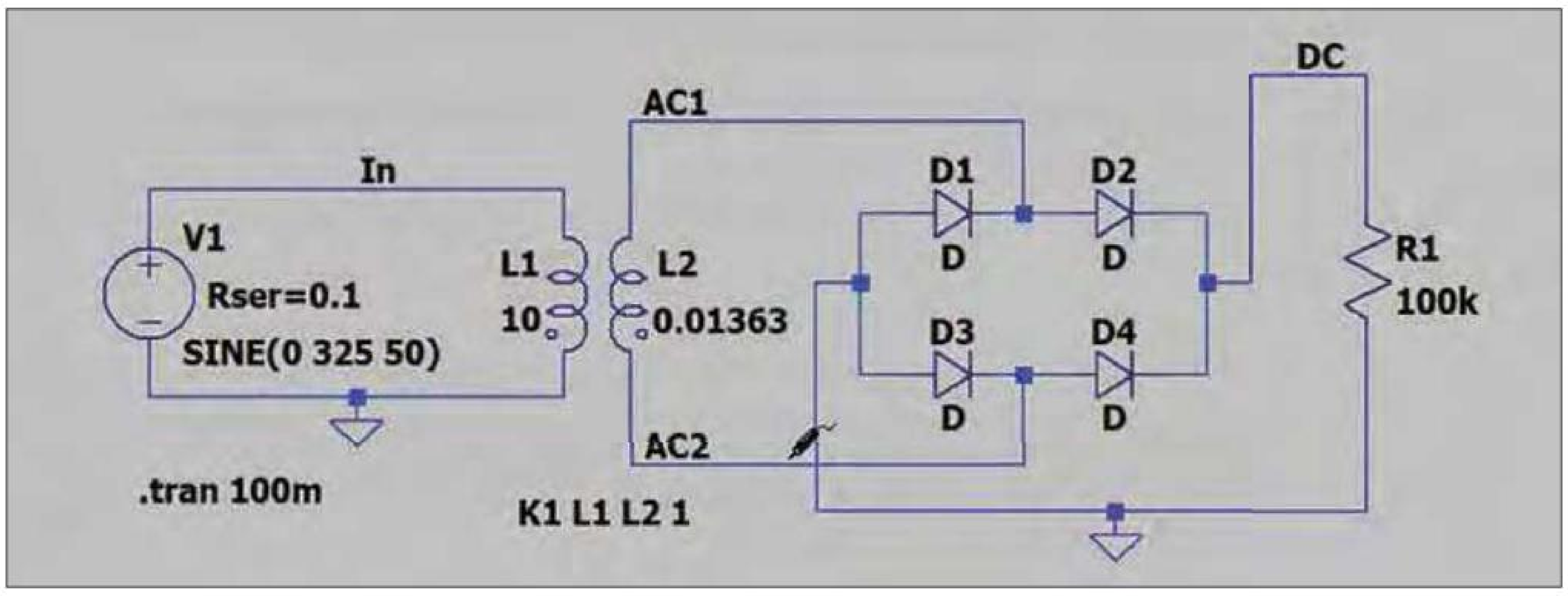

Fig.6. Transformer and bridge rectifier for use in a mains power supply.

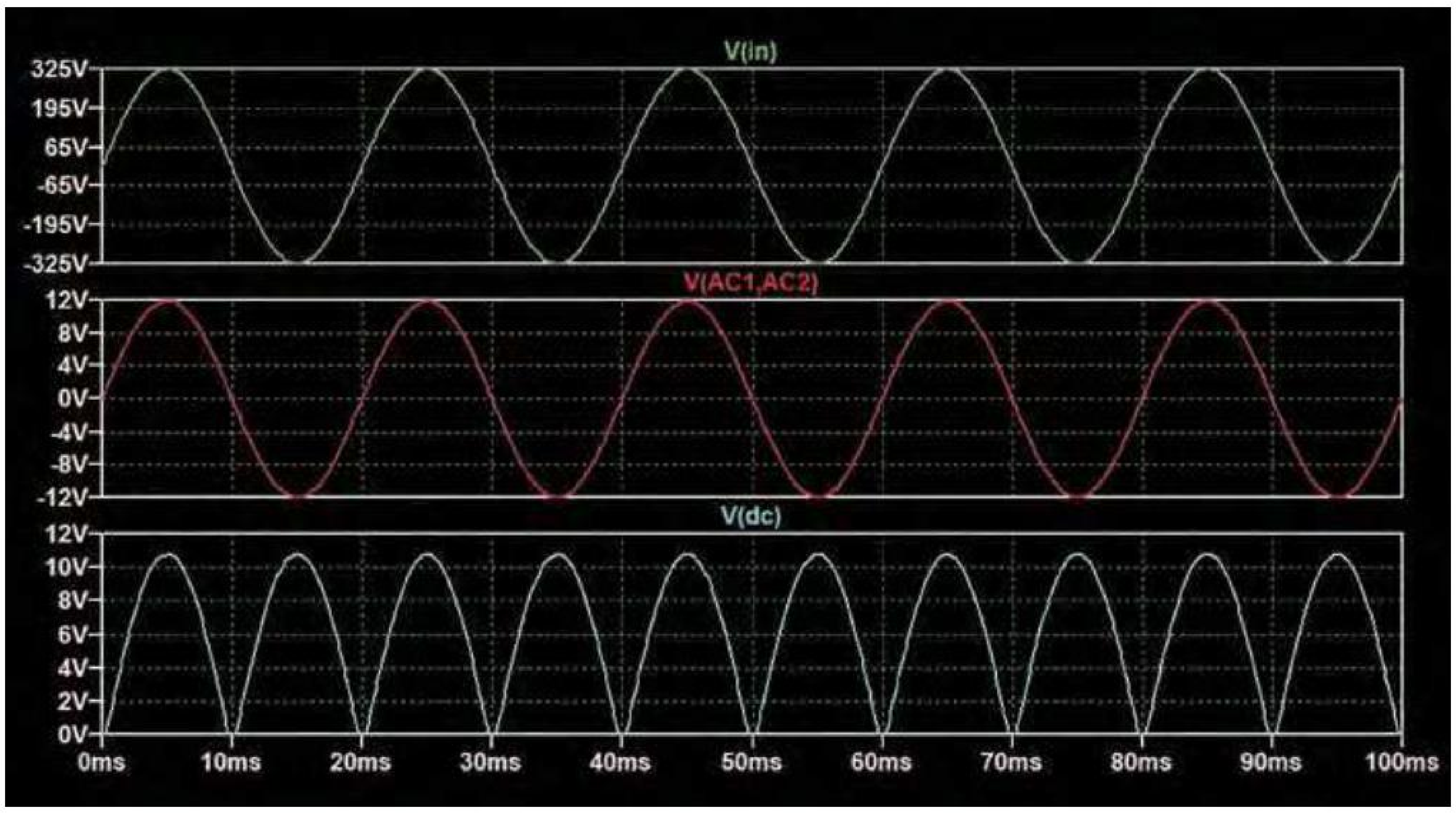

Fig.7. Simulation results from the circuit in Fig.6.

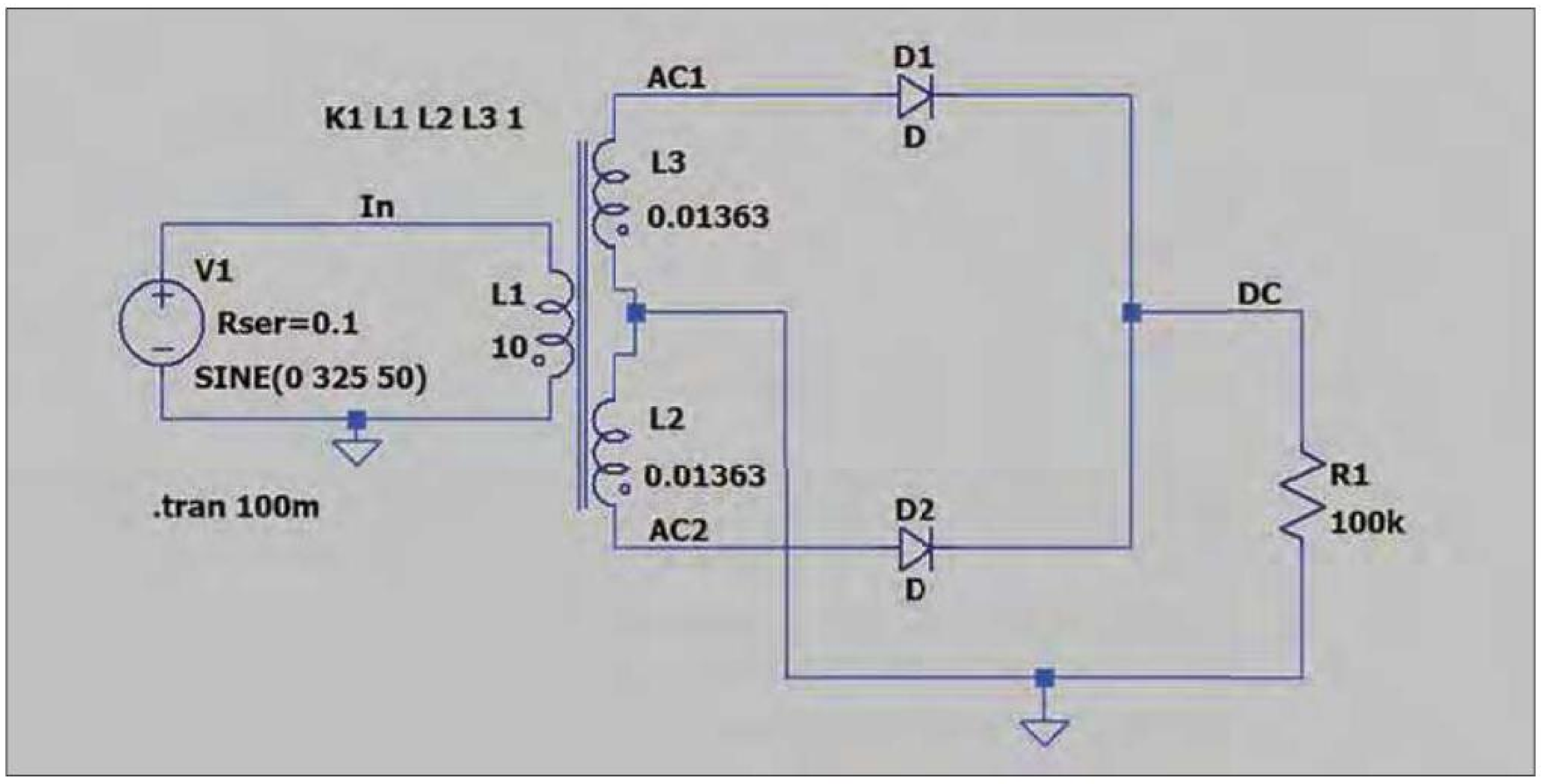

Fig.8. Full-wave rectifier using a centre-tapped transformer.

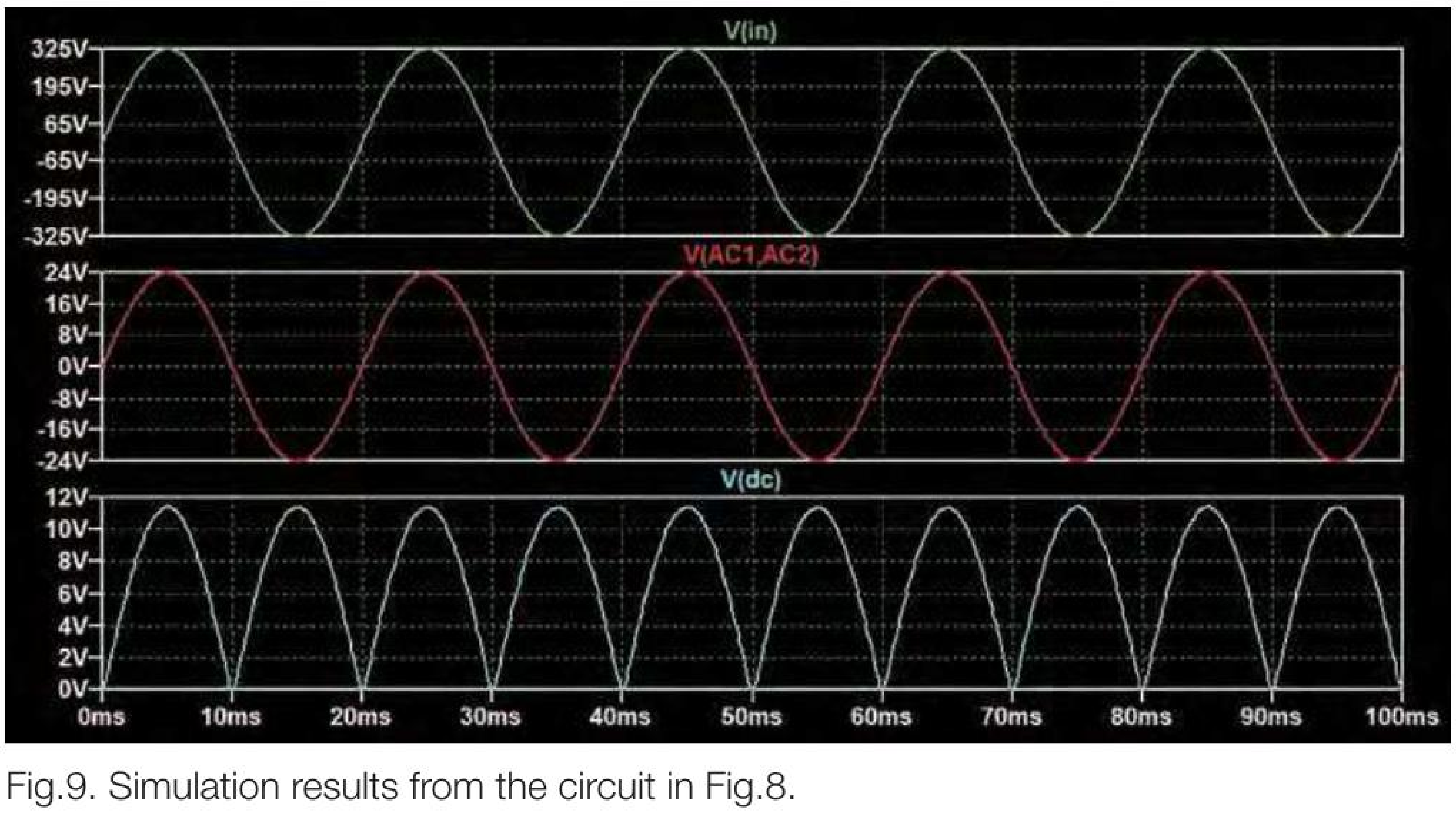

Fig.9. Simulation results from the circuit in Fig.8.

10H) is in about the right range for a mains transformer, although it does not represent a specific real device. The actual transformer inductance does not matter too much for a basic simulation of these power supply circuits (unlike in other situations, such as RF circuits), but we need to choose a value to set up the LTspice simulation.

Probing

The results from simulating the circuit in Fig.6 are shown in Fig.7. To display the AC voltage across the transformer secondary we have to specify one of the transformer terminals as the reference for measuring the voltage at the other. Otherwise, of course, LTspice uses ground as the reference for defining the voltages of displayed waveforms. A reference point can be set by right-clicking on the wire to be used as the reference and selecting 'Mark Reference' from the pop-up menu. This will place a black probe symbol on the schematic (see Fig.6). Next, click on the other wire for which the waveform is to be displayed – a red probe will be displayed when the mouse point is over a wire.

A waveform of the voltage between nodes `X` and `Y` (`X` measured from `Y`) will be titled `V(X,Y)` in the plot window rather than `V(x)` for display of the voltage waveform at node `X` with respect to ground (see `V(AC1,AC2)` in Fig.7). The red pointer and 'Mark Reference' option only appear after you have run a simulation and if you have the plot window open. Hitting the Esc key removes the black reference probe from the schematic and resumes normal ground-referenced probing for waveforms to display.

The results in Fig.7 show that the input voltage of $325V_{peak}$ results in $12V_{peak}$ across the secondary, as expected from the inductor ratio discussed above. The output from the full-wave rectifier (`D1` to `D4`), `V(dc)`, is a series of unidirectional pulses corresponding to the half-cycles of the AC waveform. Note that this is full-wave rectification because both half-cycles of the AC input contribute to the DC output.

Voltage drops

The peak voltage is around 10.8V – not the $12V_{peak}$ from the transformer. The difference is due to the forward-voltage drop of the rectifier diodes (which is about 0.6V in this case). In this example, the diodes are just LTspice default diodes, not real device models. The DC pulse peak is $12 - (2 \times 0.6) = 10.8V$. In a full power supply design, a smoothing capacitor would be connected across the rectifier output to produce a near continuous DC voltage, which would typically then be input to a regulator circuit. We have not included the capacitor here so that it is clearer how the AC waveform from the transformer is steered by the rectifier diodes to the DC output.

The circuit in Fig.6 uses a large value resistor as a load to complete the circuit and provide some diode current. This is an idealised and simplified situation compared with a real power supply with smoothing capacitor (including a reactive rather than resistive load as a significant effect). The circuit is suitable for showing the basic principles of operation of the transformer plus rectifier but does not cover all the details of a full power supply. The averaged smoothed voltage will be lower than the unidirectional DC peak (10.8V in the example above) and a regulator will need some 'headroom' (the drop-out voltage), so the maximum regulated output voltage will be lower than the peak seen in the waveform.

Centre-tap

Fig.8 shows an alternative transformer and rectifier arrangement. This uses a centre-tapped secondary and a two-diode rectifier. The two windings are both the same as in Fig.6, so the total voltage across the centre-tapped winding is 24V. Each half delivers 12V to one of the rectifier diodes, so the DC output, as with the circuit in Fig.6, is around 12V. More specifically, the peak of the unidirectional pulses is 11.4V (12 – 0.6), which is one diode drop higher than the voltage from the circuit in Fig.6. However, this circuit requires two windings and double the AC output voltage to obtain the same/similar DC voltage as the circuit in Fig.6. The circuit was popular in the past when rectifier diodes were relatively expensive (particularly in the era of thermionic valves), but less used now due to the need for the extra transformer winding.

Split supply

Although the previous circuit is not particularly useful, a slightly different centre-trapped arrangement is. If we combine a centre-trapped transformer with a bridge rectifier we can produce both a positive and negative DC output with respect to the centre tap as the reference point (ground). This circuit, together with two smoothing capacitors and two regulators, forms the basis of a split (positive and negative DC) power supply, which are very commonly used in analogue signal processing circuits, such as op amp circuits.

Fig.10 shows an LTspice schematic of a full-wave bridge rectifier with a centre-tapped transformer. The simulation results are shown in Fig.11.

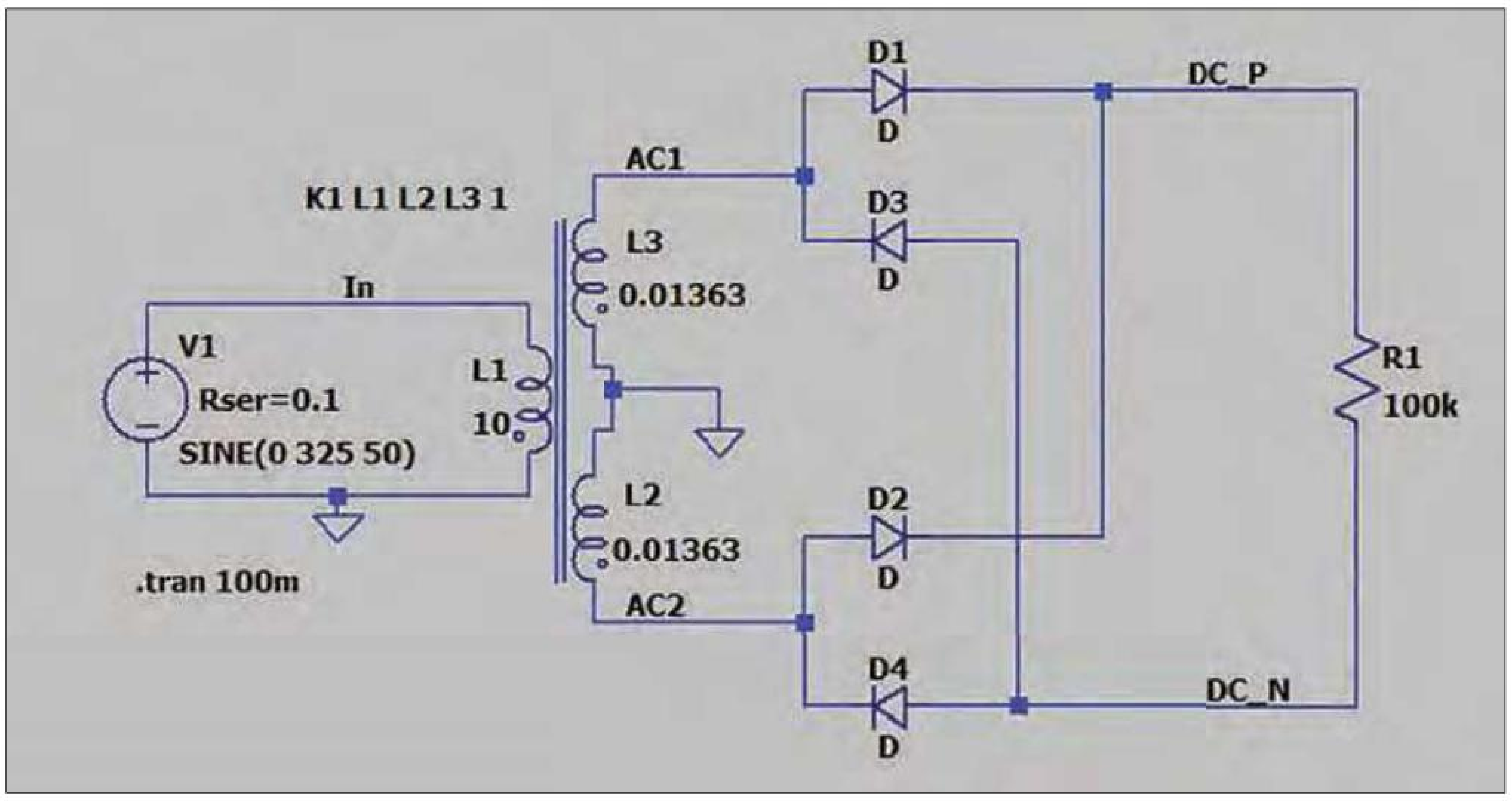

Fig.10. Full-wave rectifier with centre-tapped transformer to provide a split DC supply.

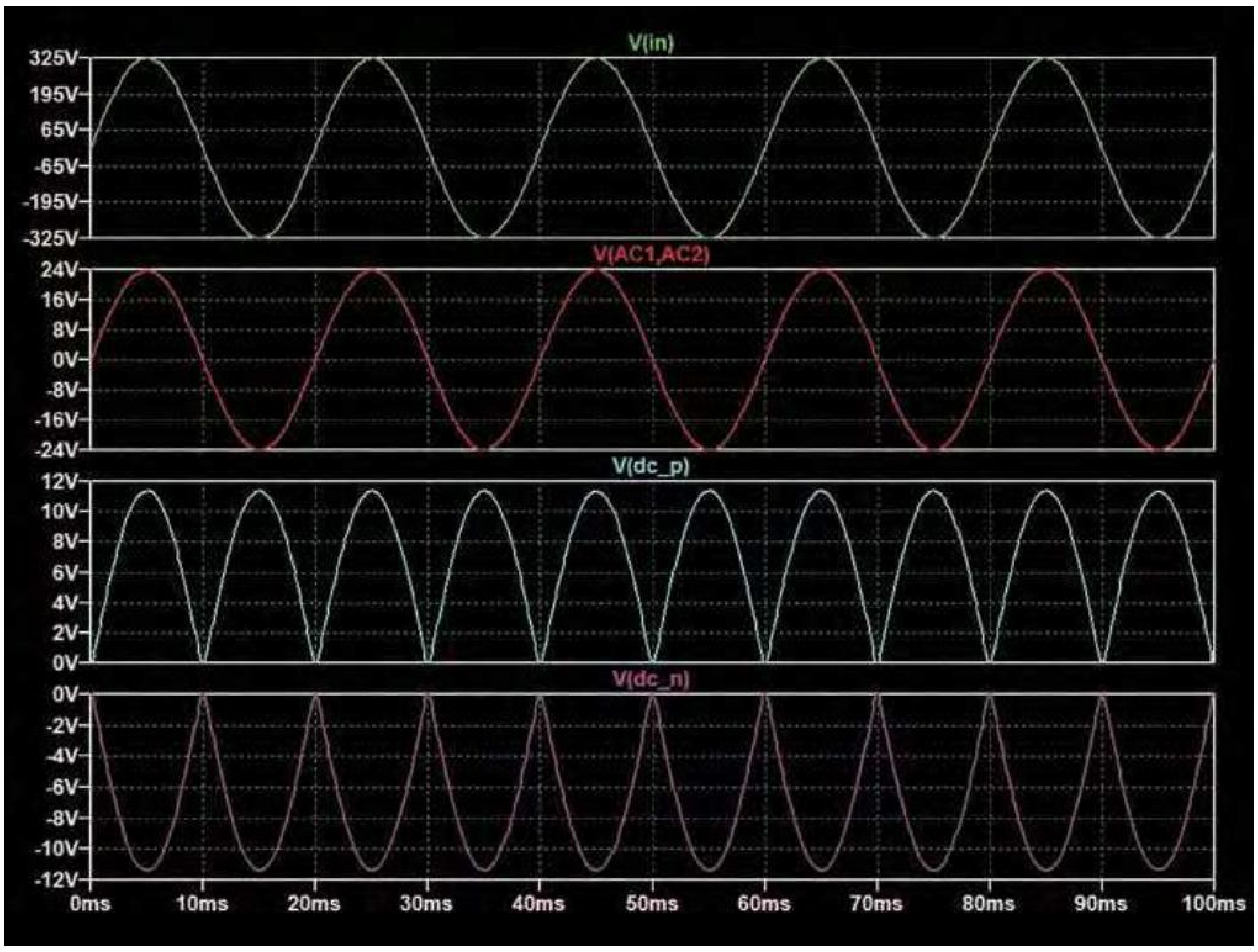

Fig.11. Simulation results from the circuit in Fig.10.

The transformer windings are the same as in the previous example, so both deliver 12V_{peak} AC. As with the circuit in Fig.8 we have 24V_{peak} AC across the two windings (`V(AC1,AC2)`). The centre tap is connected to ground and the rectifier diodes provide two sets of unidirectional pulses relative to this – positive at `DC_P` and negative at `DC_N` (see Fig.11). As with the circuit in Fig.8 the peaks are one diode forward-voltage drop below the AC peak voltage – 11.4V again in this example.

For connection to the mains, you must choose a transformer that is specified for use with the voltage and frequency of the mains in the country in which it is being used. Connecting an inappropriate transformer to the mains may result in its destruction. Mains voltage is potentially lethal and appropriate safety measures must be taken if constructing circuits designed to be connected to the mains.

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Max's Cool Beans

By Max the Magnificent

Flashing LEDs and drooling engineers – Part 17

Oooh! I have something so tantalising tasty to talk about that I'm squirming in my seat in anticipation, but first we have one last experiment to perform, peruse, and ponder on my 12×12 array of ping-pong balls.

Life, what can you do, eh?

Just to make sure that we're all tap-dancing to the same drumbeat, each of the ping-pong balls in my array is equipped with a tricolour LED. A couple of columns ago (*PE*, May 2021), we used the array to realise a first-pass implementation of *Conway's Game of Life* (*GOL*). In my previous column (*PE*, June 2021), we enhanced our original program: first, to add a smooth fade between transitions, and then to use additional colours to reflect any intergenerational states (Fig.1).

Before we proceed, it might be a good idea for you to take a look at the latest version of that program to refresh yourself as to how it performed its magic (file **CB-June21-02.txt**, which is available on the June 2021 page of the *PE* website at **https://bit.ly/3oouhbl**). Also, for your delectation and delight, I uploaded a video to YouTube showing all of this in action (**https://bit.ly/3sXsHPr**).

The way we left things was to have two cell patterns, called 'gliders', that translate themselves across the grid over the course of multiple generations. Although this was reasonably effective, I wanted to see something a tad more interesting, so I decided to randomly seed the initial population of the array, let things evolve until nothing was changing, and then start the whole thing all over again with a new randomly generated population.

There are a couple of considerations to contemplate here. The first was the approximate percentage of live cells with which we wish to populate the array. I started with two definitions: `RAND_MAX`, which I set to 100, and `RAND_CUT`, which I use as a cut-off value. Next, I created an `InitializeUniverse()` function that 'walks' through every row (indexed by `yInd`) and every column (indexed by `xInd`) in the array, performing the following actions:

```
int tmpRand = random(0, RAND_MAX);

if (tmpRand > RAND_CUT)
   Cells[yInd][xInd].nGenState = ALIVE;
else
   Cells[yInd][xInd].nGenState = DEAD;
```

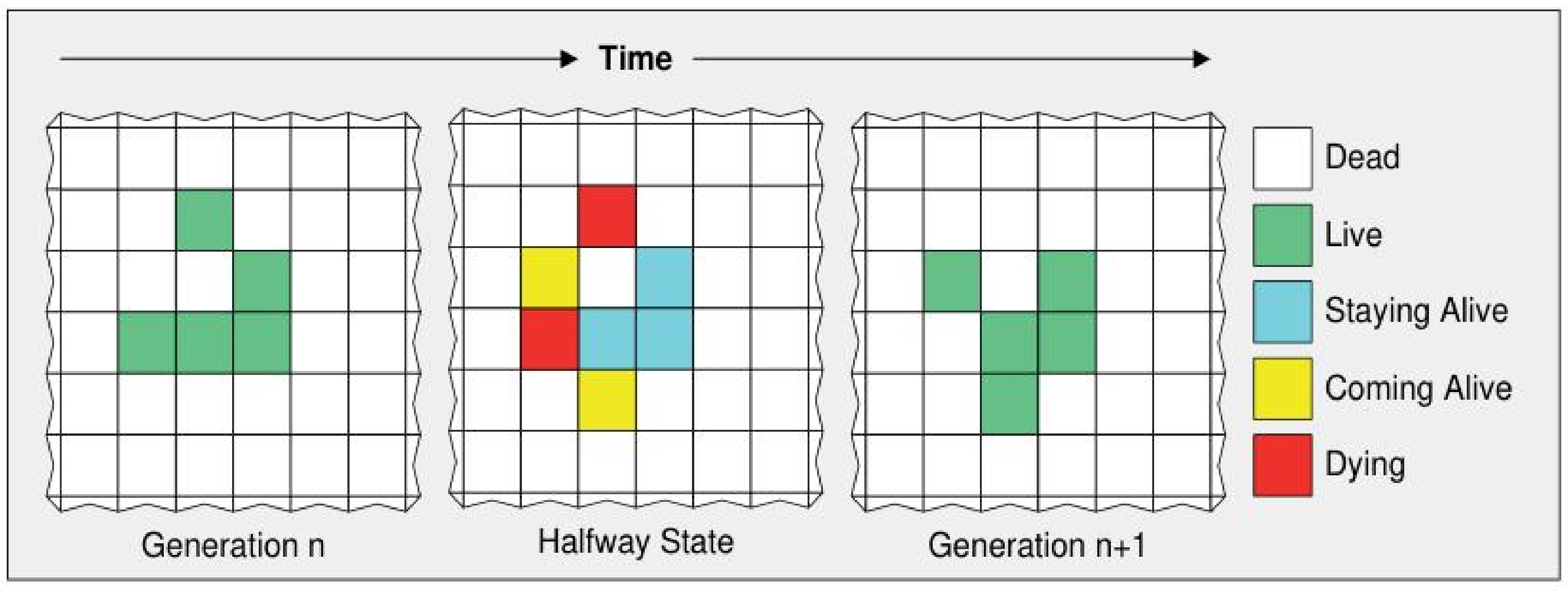


Fig.1. Representing *Conway's Game of Life* intergenerational states.

After a little experimentation, I discovered that making `RAND_CUT` too small (say 15), which resulted in ~85% of the cells being alive in the seed population, caused all the cells to die in the next generation due to overpopulation. Similarly, making `RAND_CUT` too large (say 95), which resulted in only ~5% of the cells being alive in the seed population, typically caused all the cells to die within a few generations due to underpopulation. Eventually, I settled on a `RAND_CUT` value of 85, which resulted in ~15% of the cells starting off alive in the seed population. You can see the whole program by downloading file **CB-Jul21-01.txt**, which is available on the July 2021 page of the *PE* website.

Now, observe the fact that my first-pass `InitializeUniverse()` function sets the values of the current ('n' for 'now') generation (`nGenState`) to be `ALIVE` or `DEAD`. Although this seemed to be a reasonably intuitive way to do things at first, there were some unintended consequences, including requiring us to employ our old `DisplayCurrentGeneration()` function, whose sole purpose was to display the seed generation, which seems a bit wasteful if you ask me.

After a little thought, I modified the core of the `InitializeUniverse()` function to set the values of the next (n + 1) generation (`xGenState`) as opposed to the current generation as follows (see also file **CB-Jul21-02.txt**):

```
tmpRand = random(0, RAND_MAX);

if (tmpRand > RAND_CUT)
   Cells[yInd][xInd].xGenState = COMING_ALIVE;
else
   Cells[yInd][xInd].xGenState = STAYING_DEAD;
```

As well as allowing us to dump the `DisplayCurrentGeneration()` function, this also lets us make things look a little spiffier, because we start with all the cells dead (black), then the new seed generation first fades from black to cyan, and then from cyan to green, after which we allow the game to commence evolving. Finally, at the end of each run when all the cells have died, the array returns to all the pixels being black.

I captured a video showing all of this in action (**https://youtu.be/znyvsyVUITA**). As we see, the first randomly seeded universe evolves over only a couple of generations before all of the cells shrug off this mortal coil. Similarly, for the second randomly seeded universe. However, the third random seed proved to be significantly more interesting, resulting in cell patterns that evolve over multiple generations before eventually settling into a simple 'blinker' oscillator with a period of two generations.

To be honest, I hadn't considered what would happen if the system evolved to end up containing one or more oscillators. My current code waits for things to stop changing before re-initialising the universe, but having an oscillator pattern means that things never stop changing. Just to complicate matters, different oscillators can have different periods, so what can we do to determine that we've evolved as far as we can go

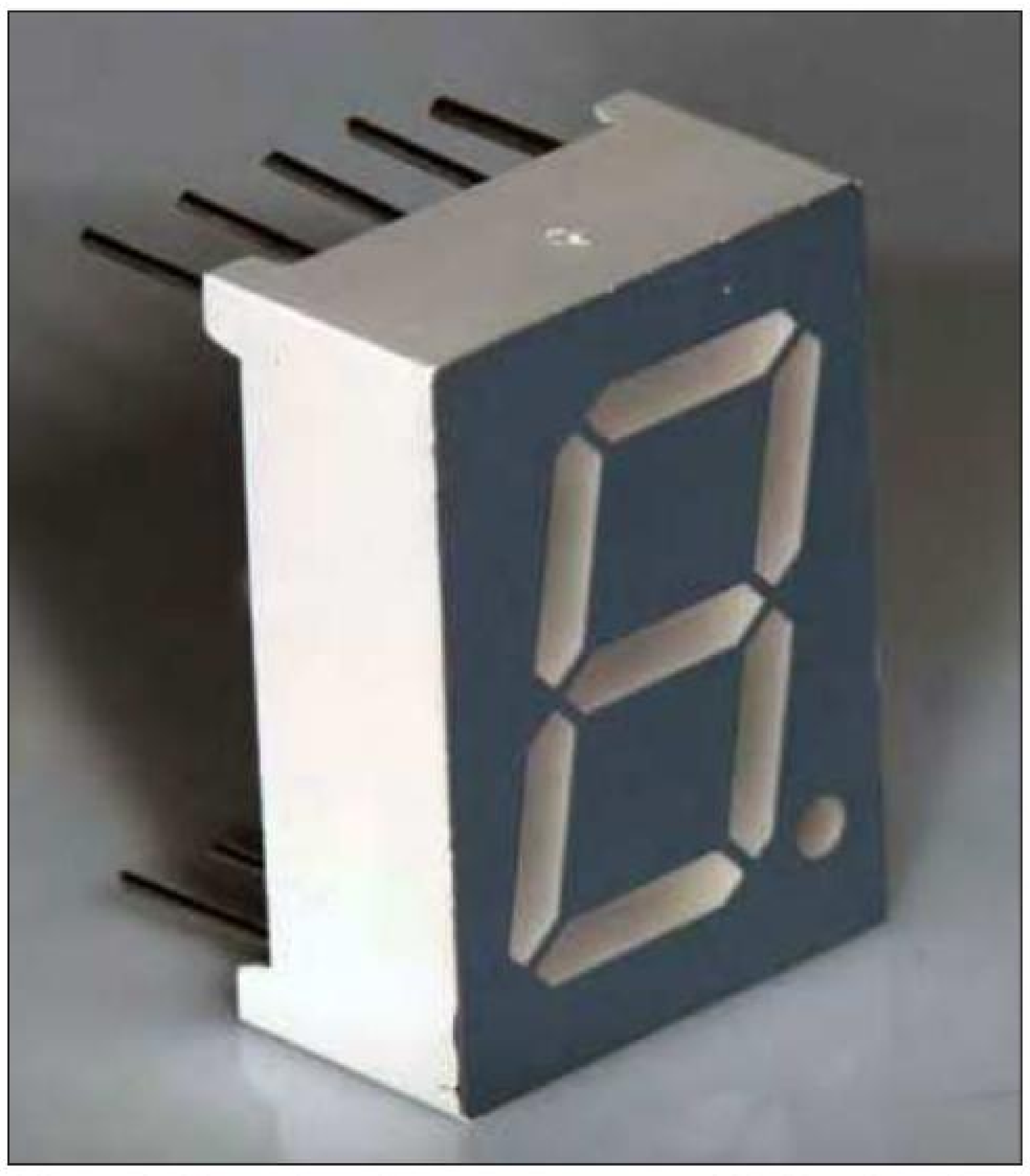


Fig.2. The classic 7-segment LED display.

and proceed to a new random seed? If you have any suggestions, this would be the perfect time for you to expound, explicate and elucidate.

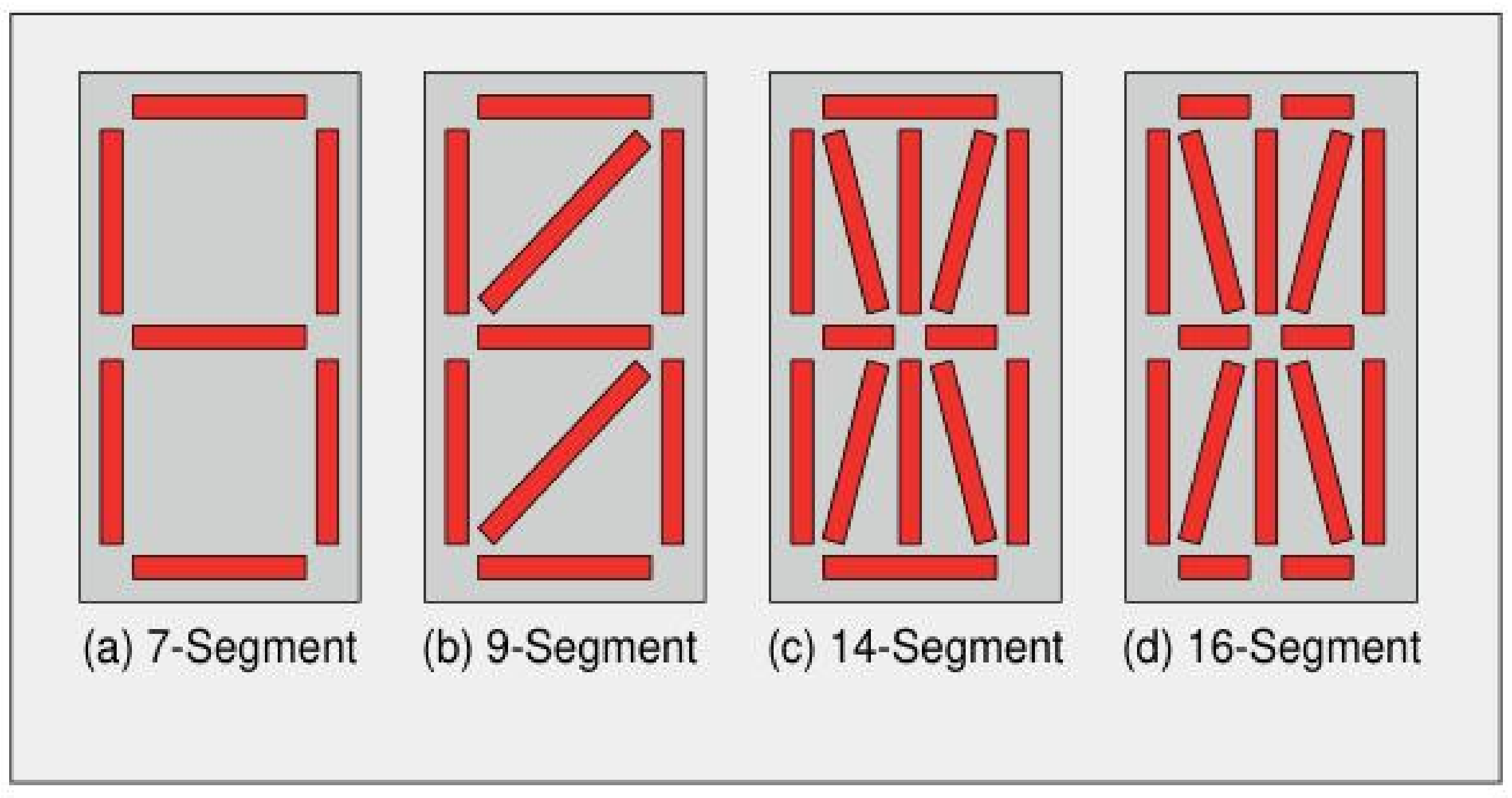
Sumptuous segments

Until recently, if I'd heard the term 'seven-segment display,' my knee-jerk reaction would have been to think of LED-based devices that can be used to display the decimal digits 0 through 9 (Fig.2 and Fig.3a). These little scamps originated in the 1970s and remain with us to this day. When these little rascals first arrived on the scene, you could have any colour you wanted, so long as that colour was red. They quickly started to appear in all sorts of devices that were considered to be amazingly cool in those days of yore, such as 4-function electronic calculators and digital watches. Unfortunately, you couldn't leave the display on because it would drain the battery, so you had to press a button on the side of the watch whenever you wished to check the time or flaunt your wrist-bound chronometer.

Did I mention how cool these displays were considered to be back in the day? I feel like an honorary member of Monty Python's *Four Yorkshiremen* sketch (**https://bit.ly/3xFUYOb**), but it's true that you can tell the young people of today that these displays were the 'bee's knees,' and they will think you are exaggerating... *and they won't believe you!*

In addition to decimal digits, 7-segment displays can also be used to represent hexadecimal values, although – in this case – the alpha characters are obliged to be presented as a mixture of uppercase and lowercase symbols: A, b, C, d, E, and F.

Of course, adding more segments allows us to represent more characters with increased fidelity, so it wasn't long before displays with 9, 14, and 16 segments started to appear on the scene (Fig.3b, Fig.3c, and Fig.3d, respectively), where the latter can be used to display all of the Arabic digits ('0' to '9'), the Latin letters ('A' to 'Z'), and a large swath of punctuation and other symbols.



(a) 7-Segment (b) 9-Segment (c) 14-Segment (d) 16-Segment

Fig.3. More and more display segments increases the range of characters that can be displayed.

Vaunting Victorians

I saw a cartoon the other day where an interviewer asks, 'So, why do you want to become an editor?' The interviewee replies, 'Well, to cut a long story short' (think about it). So, I'm going to cut a long story short. Two guys called Chris Barron and John Smout founded (and currently act as co-moderators) of a group called Smartsockets on **Groups.io** (**https://bit.ly/2PPnVGl**).

The Smartsocket concept is for a software and hardware system for driving multi-segment alphanumeric displays. Each digit is equipped with its own simple PIC microcontroller. Via simple ASCII-type instructions and industry-standard protocols — coupled with built-in fonts and transition effects — it is possible to use Smartsockets to produce arrays comprising many display devices of similar and different types.

Some time ago, John discovered that a guy called George Lafayette Mason filed a patent for 21-segment displays in 1898. This patent was eventually granted in 1901 (**https://bit.ly/3gWHl7s**). The original versions of these bodacious beauties involved 21 small incandescent bulbs (one per segment), where the bulbs were controlled by a complicated electromechanical switch that could activate various groups of segments to represent different characters as required (Fig.4).

After John became aware of this 21-segment concept, he decided to add a tricolour LED version to the Smartsockets portfolio, and this work continues apace.

Great minds

Although I love the Smartsocket concept, I've never been a PIC man myself. Also, rather than having a separate microcontroller for each digit, I tend to use a single microcontroller – like an Arduino – to control multiple displays. My chum Steve Manley is of like mind. 'Great minds think alike,' as they say (of course, they – whoever 'they' are – also say that 'Fools seldom differ,' but I'm sure they weren't talking about us).

To cut another long story short, Steve has created his own version of the 21-segment Victorian display board (Fig.5a) boasting 35 tricolour WS2812B-2020 LEDs (one each for the seven smaller segments and two each for the 14 larger segments). These boards are 50mm wide and 64mm tall. Furthermore, Steve designed a 3D printed shell that mounts on the face of the board to provide a 10mm separation between the LEDs and a diffuser attached to the front of the shell.

Steve has shared his cunning creations with yours truly, and both of us are in the process of creating 10-character droolworthy displays, which – it has to be said – look rather amazing, as I'm sure you will agree when you get to see them in future columns.

Taking control

Steve and your humble narrator have competitively created complementary WS2812 LED-based projects in the past. Generally speaking, the ground rules for these projects have been the same (eg, number, location and orientation of the LEDs), but we've gone different ways with regard to the underlying hardware (in the form of the microcontroller development platforms we've used), the software (in the form of the LED libraries we've employed), and any additional augmentations, like sound-processing strategies and suchlike. As a result, not surprisingly, it's proved difficult, if not impossible, for us to share code and detailed design ideas.

In the case of our Victorian displays, we've decided to use the same core

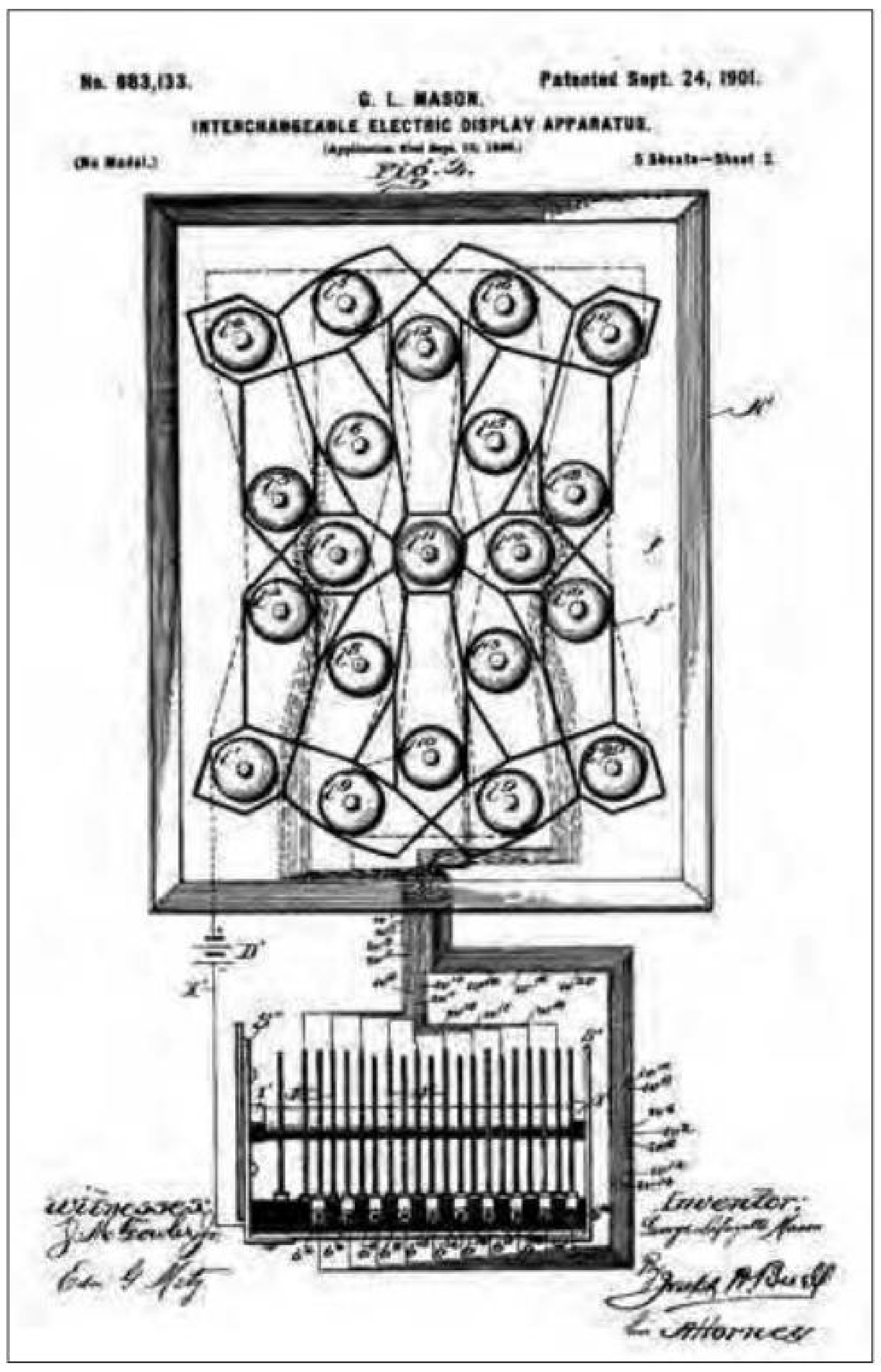


Fig.4. Copy of an original 21-segment display patent from 1901.

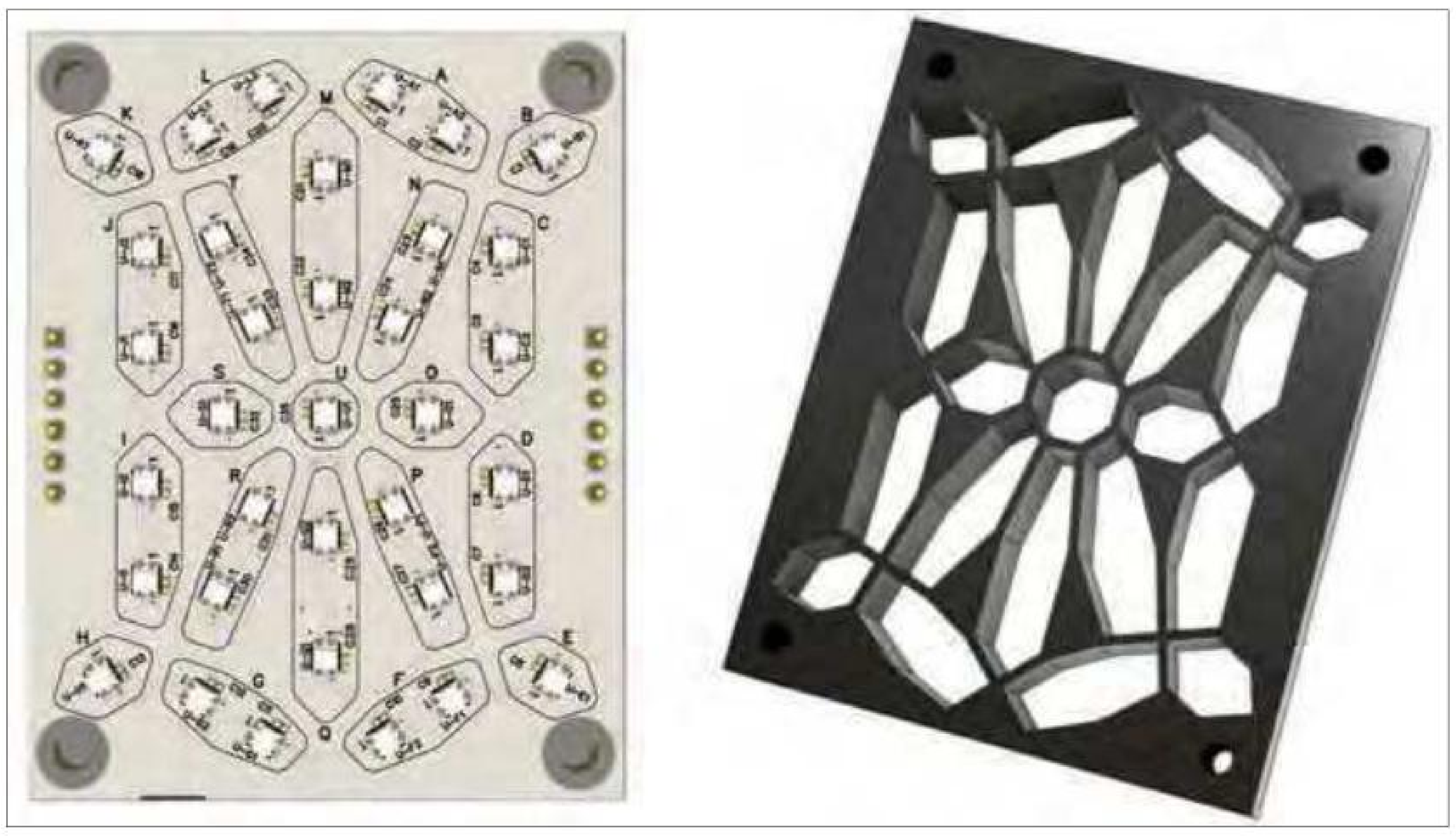


Fig.5. LED board and 3D printed shell for 21-segment display: a) LED board (left); b) 3D printed shell (right).

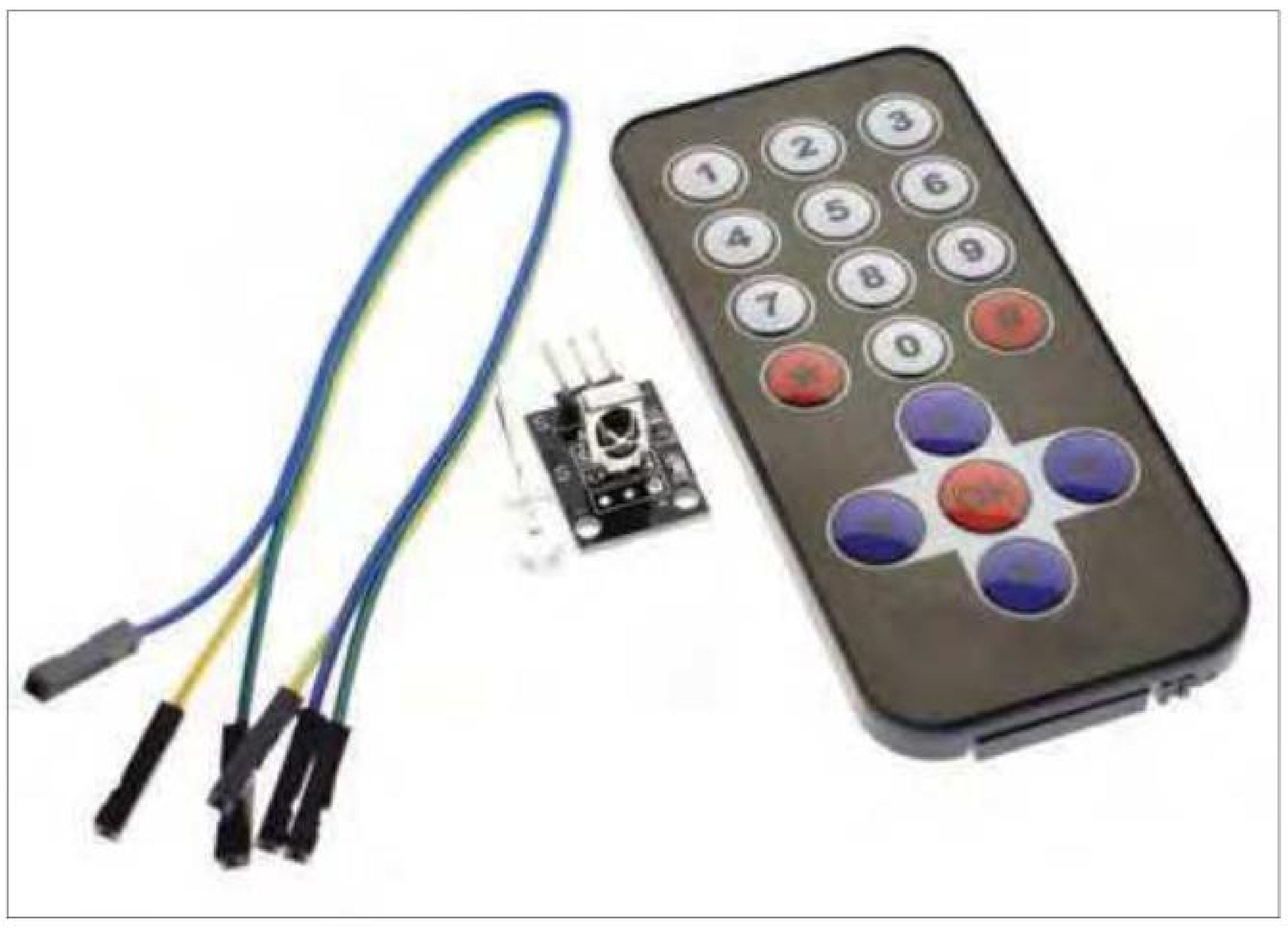


Fig.6. Using a cheap-and-cheerful IR controller makes life much simpler.

hardware, thereby allowing us to jointly work on the software together (I think that the 'together' in this sentence was redundant, but I don't care). As part of this, we decided to create a control board that would not only satisfy the immediate needs of our 10-character displays in the present, but that will also be applicable to a wide range of other projects in the future.

When it comes to microcontrollers, Steve is currently favoring the Teensy 3.2 from PJRC (**https://bit.ly/3h5tifW**). This boasts a 32-bit Arm Cortex-M4 running at 72MHz (it can be overclocked to 96MHz) with 256KB of Flash memory, 64KB of SRAM, and 2KB of EEPROM. Personally, I prefer a Teensy 3.6, which has more I/O pins and features a 32-bit Arm Cortex-M4F (ie, it has a floating-point unit (FPU)) running at 180MHz (it can be overclocked to 240MHz) with 1MB of Flash, 256KB of SRAM, and 4KB of EEPROM. As a compromise, we decided that our control board would support both, although only one at a time, of course.

Next, we had a brain-stem-storming session regarding any relevant features and functionalities we've variously employed on previous projects. These include using a highly accurate real-time clock (RTC) chip to keep track of the date and time when power is removed from the system. Also, having a light-dependent resistor (LDR) that can be used to vary the brightness of the display depending on the level of ambient light.

We also desire access to an audio input so that we can use sound to control the patterns being displayed. On one of our previous competitive projects, I used a line-in audio input in my design, while Steve used a microphone in his implementation, so we decided to support both options with our new board. Also, we've both used MSGEQ7 audio spectrum analyser chips in past projects (**https://bit.ly/3h23QYv**). More recently, Steve has been experimenting with a sophisticated audio codec chip coupled with the Teensy Audio Library (**https://bit.ly/3tpnrEA**), and we decided that Steve's approach offers the best route for the future.

With regard to controlling the system using pushbuttons, one of my earlier projects used a 3-button scheme while another employed a 6-button approach. For the purposes of our new control board, we compromised on a 5-button solution that Steve has evolved over a number of his recent projects. We can use the left, right, up, down, and 'OK' buttons to access menus, select modes and effects, and enter values (eg, date and time). Even better, one of Steve's recent projects also had the ability to support a cheap-and-cheerful infrared (IR) controller (**https://amzn.to/3b6iJ8x**). In addition to left, right, up, down, and 'OK' buttons (Fig.6), this also has buttons for the numbers 0 to 9, which makes performing tasks like entering the date and time much quicker and easier, so we've decided to incorporate this capability into our new board.

As part of this, we decided to add a Seeedunio XIAO from Seeed Studio (**https://bit.ly/2QYem8v**) to handle the IR control functions (Steve previously used an Adafruit Trinket for this purpose). While the XIAO is only the size of a regular postage stamp, it packs a punch with a 32-bit Arm Cortex-M0+ running at 48MHz with 256KB of Flash and 32KB of SRAM. In reality, we could probably have handled the IR control functions using the main Teensy, but sometimes it's easier to employ a 'divide and conquer' approach. Also, although the XIAO is total overkill for use as an IR controller, it's extremely cheap and – like the Teensy microcontrollers – can be programmed using the Arduino's integrated development environment (IDE). Plus, it's always useful to have spare compute capability available in case one needs it in the future.

Based on all of the above, along with a raft of other considerations, Steve has designed an amazingly cool board that will serve us well for many projects to come (Fig.7).

At the time of this writing, we have no plans to make this control board available as a product – nor are we going to sell the Victorian displays themselves – all of this is just a hobby project. On the other hand, I will be sharing some of the nitty-gritty details in my *Cool Beans* columns because you may find them useful for your own projects.

Also, some extremely exciting news is that we've just designed a special *SMAD* (*Steve and Max's Awesome Display*) board with 45 low-current tricolour LEDs that can be driven by a regular Arduino. This board can be used to prototype the sort of special effects we'll be using on our Victorian displays, and we will be making it available for purchase via the *PE* store (all will be

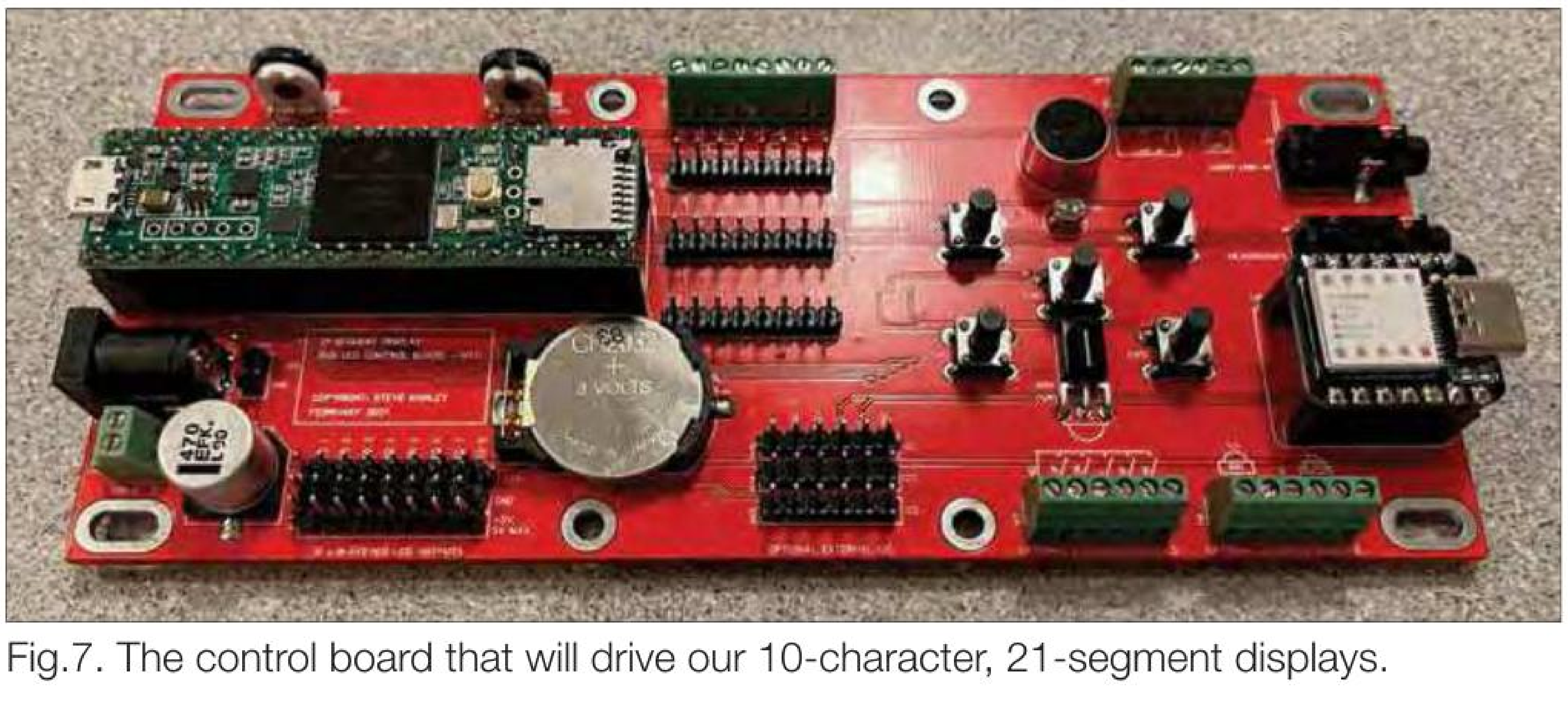


Fig.7. The control board that will drive our 10-character, 21-segment displays.

revealed in my next *Cool Beans* column in *PE*, August 2021).

Some nitty-gritty details

In the short time remaining to us in this column, let's take a brief stroll around the control board to peruse and ponder particular points of interest. On the left-hand side we see a Teensy 3.6 plugged into some headers. This can be removed and replaced with a Teensy 3.2 if required. On the right-hand side we see the XIAO, which is also plugged into some headers, and which will be used to process the incoming signals from the IR controller.

Just behind the Teensy are two potentiometers, which can be used to adjust the brightness of the display and its audio sensitivity (or anything else we program them to do). Just in front of the Teensy is a coin-cell battery to keep the RTC running when power is removed from the system.

With regard to the RTC, in earlier projects I've used the ultra-precise ChronoDot breakout board (BOB) from Adafruit (**https://bit.ly/3tkCHml**). Meanwhile, Steve has been using the DS3231 integrated circuit (IC) on his custom boards. The DS3231 is a low-cost, extremely accurate I^{2}C RTC with an integrated temperature-compensated crystal oscillator (TCXO) and crystal. By some strange quirk of fate, this is the same chip that's used on the ChronoDot.

The DS3231 and any other surface-mount ICs are presented on the bottom side of the board and so are not visible in Fig.7. These ICs include an SGTL5000 low-power stereo audio codec from NXP, an LS119 switch debounce IC from LogiSwitch, and an SN74HCT245 octal bus transceiver acting as a voltage-level shifter from Texas Instruments.

Observe the five control buttons that are located in the middle-right of the board. It's also possible to connect five more case-mounted buttons in parallel via the green screw block connectors. Above the middle button is the LDR and an electret microphone; below the middle button we see the IR detector.

The way the board has been designed, most of its features and functions, such as the IR control, the RTC and the audio codec are optional. Also, as opposed to soldering components like the microphone, LDR and IR detector directly onto the board, these can be mounted remotely and connected via the green screw-block terminals.

The header pins to the right of the Teensy grant access to any uncommitted microcontroller pins. The header pins to the lower-right of the coin-cell battery allow additional I^{2}C-enabled sensors and other devices to be connected to the board. Finally, observe the 8×3 cluster of header pins to the lower left of the coin cell battery. These are presented as eight groups, each consisting of 5V, 0V and a data signal that can be used to drive WS2812 tricolour LEDs. The SN74HCT245 discussed earlier is used to convert the 3.3V outputs from the Teensy to the 5V signals required to drive the LEDs. The reason for using this octal buffer is that the Teensy is capable of driving eight strands of LEDs simultaneously. We will be delving deeper into this capability in my next *Cool Beans* column. In the meantime, as always, I welcome any and all comments, questions, and suggestions.

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

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Max's Cool Beans cunning coding tips and tricks

Before we jump into the fray with gusto and abandon (and aplomb, of course), I was recently chatting with my chum Steve Manley who features so prominently in my main *Cool Beans* column. I'm not sure how we got into this particular topic, but Steve taught me a very cunning coding trick as follows...

I've reached my limit!

It very often happens in my programs that I have an integer variable that I use as a pointer (or index) to a number of elements in an array or some such entity. For example, let's say we have ten elements of something or other numbered from 0 to 9. For clarity in our code and to make it easy to modify in the future, we might define `NUM_E` ('number of elements') as being 10 and `MAX_E` ('maximum element') as being 9. (We could also define `MIN_E` as being 0, but we typically just use 0.)

Let's suppose our integer pointer is called `PtrP`. Sometimes we want to increment this pointer by adding 1 to its current value. Of course, when its current value is 9, we want its incremented value to 'wrap around' to be 0. In this case, remembering that the `%` modulo operator returns the remainder from an integer division, and based on our discussions from an earlier column (*PE*, March 2021), prior to my discussions with Steve, I might have used a statement like the following:

```
// Increment the pointer
PtrP = (PtrP + 1) % NUM_E;
```

On other occasions, we want to decrement our pointer by subtracting 1 (or adding –1) to its current value. In this case, when its current value is 0, we want its decremented value to 'wrap around' to be 9. Once again, based on our earlier discussions, I might have used a statement like the following:

```
// Decrement the pointer
PtrP = (PtrP + MAX_E) % NUM_E;
```

Well, Steve pointed out that the way he does this, assuming he has a variable called `Delta`, which may be assigned a value of +1 or –1 if we wish to increment or decrement, respectively, is as follows:

```
// Increment/Decrement the pointer
PtrP = (PtrP + NUM_E + Delta) % NUM_E;
```

Good Golly, Miss Molly! This is so simple... so succinct... so sharp. I love it!

Thanks for the memory!

I don't know about you, but one of the things I worry about is losing my memory as I get older. This has happened to my mother's sister – my auntie Shirley – who now lives in a home because she can no longer take care of herself and she no longer recognises any members of our family, including her own children. Fortunately, my 90-year-old mother still has a mind like a trap. In fact, my mom's memory is so good that sometimes she remembers things that haven't even happened yet!

This meandering musing was triggered by my thinking of computer memory. In my main *Cool Beans* column, we noted that the Teensy – like virtually all microcontrollers – contains three types of memory. First, we have the Flash, which is used to store the main program (a.k.a. sketch). Next, we have the SRAM (static random-access memory), which is where the main program creates, stores, and manipulates variables when it runs. Finally, we have a form of memory that most beginners don't even know about and rarely use – a small amount of EEPROM (electrically erasable programmable read-only memory) – in which programmers can store modest quantities of long-term information.

The problem with SRAM is that it's volatile, which means it forgets its contents when power is removed from the system. Flash memory is non-volatile, which means it remembers its contents when power is removed, but this is where the main program is stored. Suppose we decide to write a program that measures the ambient temperature once every hour and we want to save these values in such a way that we can retrieve them later, even if the microcontroller's power supply fails at any time. In this case, one option would be to use the EEPROM.

Similarly, in the case of the 10-character 21-segment Victorian displays that Steve and I are constructing, we want to use byte-sized unsigned integer values to keep track of a variety of user settings, like the preferred date format (eg, 0 = YYYY/MM/DD, 1 = MM/DD/YYYY, 2 = DD/MM/YYYY) and time format (eg, 0 = 12-hour, 1 = 24-hour) and location (eg, 0 = UK, 1 = USA) and how we are going to handle summertime (eg, 0 = by hand, 1 = automatic) and so forth. (FYI, 'summertime' is called 'Daylight Saving Time' (DST) in the US and 'British Summer Time' (BST) in the UK.)

Of course, we will establish default values for these settings in our main program. However, we also want to allow the user to change these settings when the program is running, and we want our display to remember these user-defined values when power is removed from the system. Once again, one way to achieve this is to use the EEPROM.

Remember that the term 'byte' refers to an 8-bit quantity. As we discussed in the main *Cool Beans* column, Teensy 3.2 and 3.6 microcontrollers have 2KB (2,048 bytes numbered from 0 to 2,047) and 4KB (4,096 bytes numbered from 0 to 4,095) of EEPROM, respectively.

If we want to use this EEPROM in programs, we first need to include a special library that's provided as part of the Arduino's IDE:

```
#include <EEPROM.h>
```

Now, let's suppose we wish to write a value of 128 into the EEPROM at its address 0. We could do so using the following statement:

```
EEPROM.write(0, 128);
```

Alternatively, if we declare an integer variable called `Address` to which we assign a value of 0, along with a byte-sized variable called `Data` to which we assign a value of 128, we could use the following statement:

```
EEPROM.write(Address, Data);
```

Contrawise, if at some stage we wish to read a byte of data out of the EEPROM's address 0, we could use either of the following statements:

```
Data = EEPROM.read(0);
Data = EEPROM.read(Address);
```

You can read more about the EEPROM library in the Arduino reference guide (**https://bit.ly/2QYwsHO**) and on the Teensy website (**https://bit.ly/3y0L8H1**), but just knowing the `read()` and `write()` functions provides us with enough knowledge to be dangerous.

How many copies?

In reality, we are going to have a bunch of different settings we wish to keep track of. Purely for the sake of these discussions, however, let's assume that we have only the four byte-sized settings we discussed earlier: `vdDate`, `vdTime`, `vdLocation`, and `vdSummer` (where 'vd' stands for 'Victorian Display'). In fact, we are going to want to keep three copies of these settings (as opposed to 'copies,' we might think of these as versions or instantiations). First, we will need a copy of our default values, which we will store in the program itself. Second, we will need a copy of the user-defined values, which we will store in the EEPROM. Finally, we will need a working copy of the values we are actually using.

This may sound a little confusing at first, but it makes perfect sense when you think about it. Let's suppose that we load our program onto a new microcontroller. In this case, when we run the program for the first time, there won't be anything useful stored in the EEPROM. When we detect this fact (we will discuss this further in my next *Tips and Tricks* column), we will load our default values both into the EEPROM and into our working values.

Since this is the first time that we've run the program, we will probably take this opportunity to modify the various settings to be just the way we like things. Of course, we might make additional changes in the future. The point is, for each setting we change, we will override the corresponding working value and EEPROM value with this new value.

Some days you feel like an array

When we come to copy the settings to and from the EEPROM, for example, it's easier if we think of things as being an array. For example, assuming that we've defined `NUM_SETTINGS` as 4, we might define our default settings and our working settings in the form of arrays as follows:

```
uint8_t DefSettings[NUM_SETTINGS];
uint8_t WrkSettings[NUM_SETTINGS];
```

Let's assume that we are using locations 0, 1, 2 and 3 in these arrays to keep track of our `vdDate`, `vdTime`, `vdLocation`, and `vdSummer` settings, respectively. We won't worry about how we initialise things here, let's just assume that our `DefSettings[]` array has been loaded with appropriate values. If we wish to copy the values from the `DefSettings[]` array into the `WrkSettings[]` array, we could use:

```
for (i = 0; i < NUM_SETTINGS; i++)
   WrkSettings[i] = DefSettings[i];
```

Similarly, if we wish to copy the values from the `DefSettings[]` array into the EEPROM, we could use:

```
for (i = 0; i < NUM_SETTINGS; i++)
   EEPROM.write(i, DefSettings[i]);
```

And, of course, if we wish to copy the values from the EEPROM into our `WrkSettings[]` array, we could use:

```
for (i = 0; i < NUM_SETTINGS; i++)
   WrkSettings[i] = EEPROM.read(i);
```

Some days you feel like a struct

The problem with thinking of things as arrays is that it doesn't make our code very readable later on. For example, what are we going to think if we are reading the main program and we see something like:

```
if (WrkSettings[2] == 0)...
```

Remember that, in the real application, we might have tens or hundreds of such settings. Thus, it would make our lives a lot easier to be able to think of our values as fields and say something like:

```
if (WrkSettings.vdLocation == UK)...
```

As you may recall, we introduced the concepts of `typedef` (type definitions), `enum` (enumerated types), and struct (structures) in *Tips and Tricks*, *PE*, December 2020. Based on this, we might decide to define and declare some structures as follows:

```
typedef struct Settings
{
   uint8_t vdDate;
   uint8_t vdTime;
   uint8_t vdLocation;
   uint8_t vdSummer;
};

Settings DefSettings;
Settings WrkSettings;
```

Once again, we won't worry about how we initialise things here, let's just assume that our `DefSettings` structure has been loaded with appropriate values. Once we have the appropriate values in our `WrkSettings` structure, we're good to go. The problem comes when we wish to load this structure. If we are loading it from our `DefSettings` structure, we are going to have to use a series of statements like:

```
WrkSettings.vdDate =
      DefSettings.vdDate;
WrkSettings.vdTime =
      DefSettings.vdTime;
   :
   etc.
```

Alternatively, if we are loading the values in our `WrkSettings` structure from the EEPROM, we are going to have to use a series of statements like:

```
WrkSettings.vdDate =
      EEPROM.read(0);
WrkSettings.vdTime =
      EEPROM.read(1);
   :
   etc.
```

It doesn't take long to realise that, if we have tens or hundreds of settings, this is quickly going to become a pain in the nether regions and – trust me – this is the last place we want to have a pain. If only there was some way in which we could treat our settings both as an array *and* as a structure...

Let's form a union!

It's almost as if the folks who created the C programming language read our minds because they created a special data type called `union` that allows us to store different types of data in the same memory locations. Another way to think about this is that a union allows us to view the same memory locations in different ways. For example, consider the following (remember that `NUM_SETTINGS` has been defined as 4):

```
typedef union Settings
{
   struct
   {
      uint8_t vdDate;
      uint8_t vdTime;
      uint8_t vdLocation;
      uint8_t vdSummer;
   } vds;

   uint8_t vda[NUM_SETTINGS];
};

Settings DefSettings;
Settings WrkSettings;
```

First, we define a new type in the form of a `union` that we called `Settings`. As we see, this `union` offers two different ways to view / think of / treat the same four bytes of memory. The first method is to think of these four bytes as a structure we've called `vdS`; the second approach is to think of the same four bytes as an array we've called `vdA`.

Next, we declare two variables, `DefSettings` and `WrkSettings`, both of which are of type `Settings`. As before, we won't worry about how we initialise things here. Suffice it to say that, if we determine that the EEPROM contains a valid set of settings values, we can load our working settings as follows:

```
for (i = 0; i < NUM_SETTINGS; i++)
WrkSettings.vdA[i] = EEPROM.read(i);
```

Later, in the body of the program, we can use statements like:

```
if (WrkSettings.vdS.vdLocation
      == UK)...
```

We've only touched on the power of the `union` type here because we've simply defined two different ways of looking at the same four bytes of memory. In fact, a `union` can provide three or more ways of looking at the same area of memory, where one member might think of things as 4-byte unsigned integers, another might think of each of these integers as four separate bytes, and yet another might think of things as individually named bits... and then things start to get complicated, but we can leave that for another day. As always, I welcome your comments, questions and suggestions.

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PCBs for most recent *PE*/*EPE* constructional projects are available. From the July 2013 issue onwards, PCBs with eight-digit codes have silk screen overlays and, where applicable, are double-sided, have plated-through holes, and solder mask. They are similar to photos in the project articles. Earlier PCBs are likely to be more basic and may not include silk screen overlay, be single-sided, lack plated-through holes and solder mask.

Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

In most cases we do not supply kits or components for our projects. For older projects it is important to check the availability of all components before purchasing PCBs.

Back issues of articles are available – see Back Issues page for details.

Double-sided | plated-through holes | solder mask

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PE Theremin (three boards: pitch, volume, VCA)	PETX0819	£19.50
PE Theremin component pack (see p.56, August 2019)	PETY0819	£15.00
JULY 2019		
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JUNE 2019		
Arduino-based LC Meter	04106181	£8.00
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MARCH 2019		
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+Processing Board	04101182	£8.60
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Introducing the BBC micro:bit

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IN FULL COLOUR
For Beginners of Any Age
Python Coding on the BBC micro:bit
Jim Gatenby

PYTHON CODING ON THE BBC MICRO:BIT

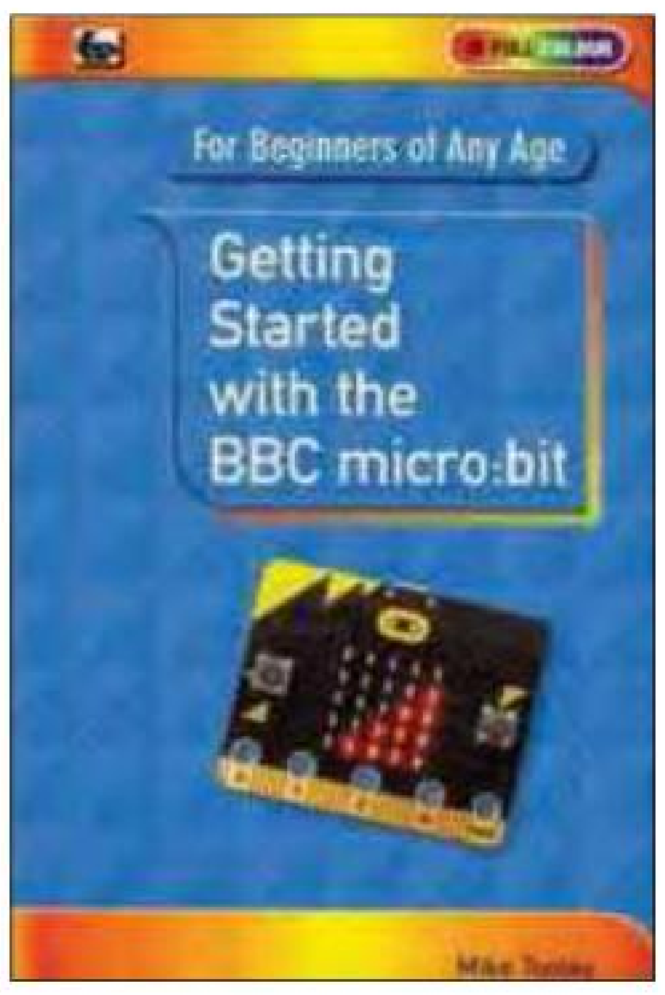
Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

Among the many topics covered are: main features of the BBC micro:bit including a simulation in a web browser screen; various levels of programming languages; Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; scrolling messages, creating and animating images on the micro:bit's LEDs; playing and creating music, sounds and synthesized speech; using the on-board accelerometer to detect movement of the micro:bit on three axes; glossary of computing terms.

This book is written using plain English, avoids technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

118 Pages **Order code PYTH MBIT** £7.99



GETTING STARTED WITH THE BBC MICRO:BIT

Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm × 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, reaction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter, together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

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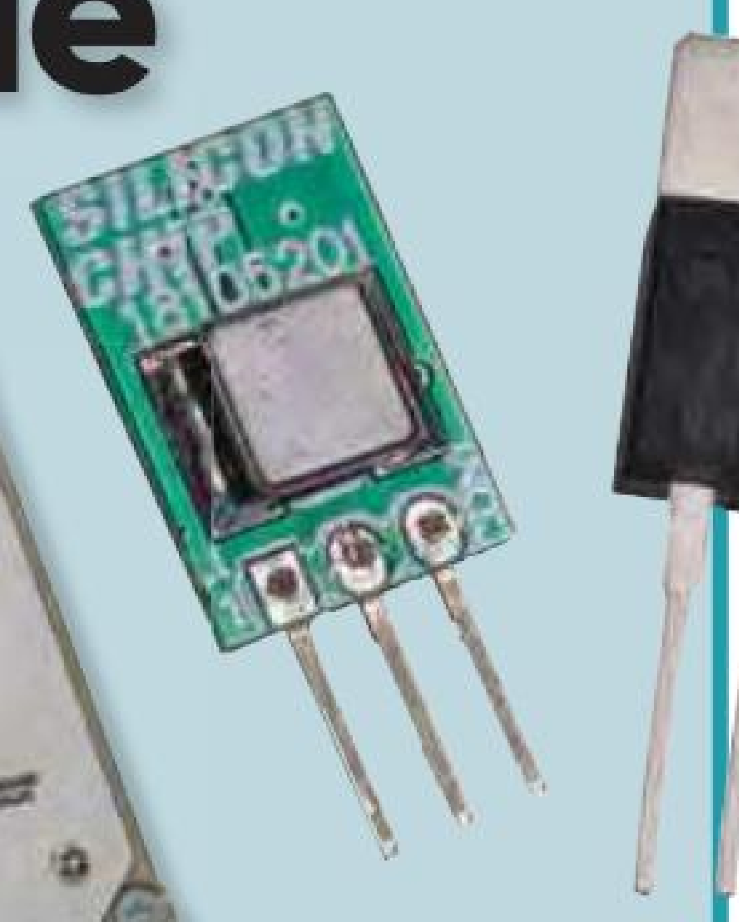
Next Month – in the August issue



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QUARTER TO
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SET
DOWN
UP
SILICON CHIP
OL' TIMER II

Ol' Timer

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KickStart Part 4: Introducing the Arduino Pro Mini

This fourth *KickStart* instalment shows you how to make use of the diminutive Arduino Pro Mini and we'll show you how to start making use of this tiny microcontroller in your own projects.

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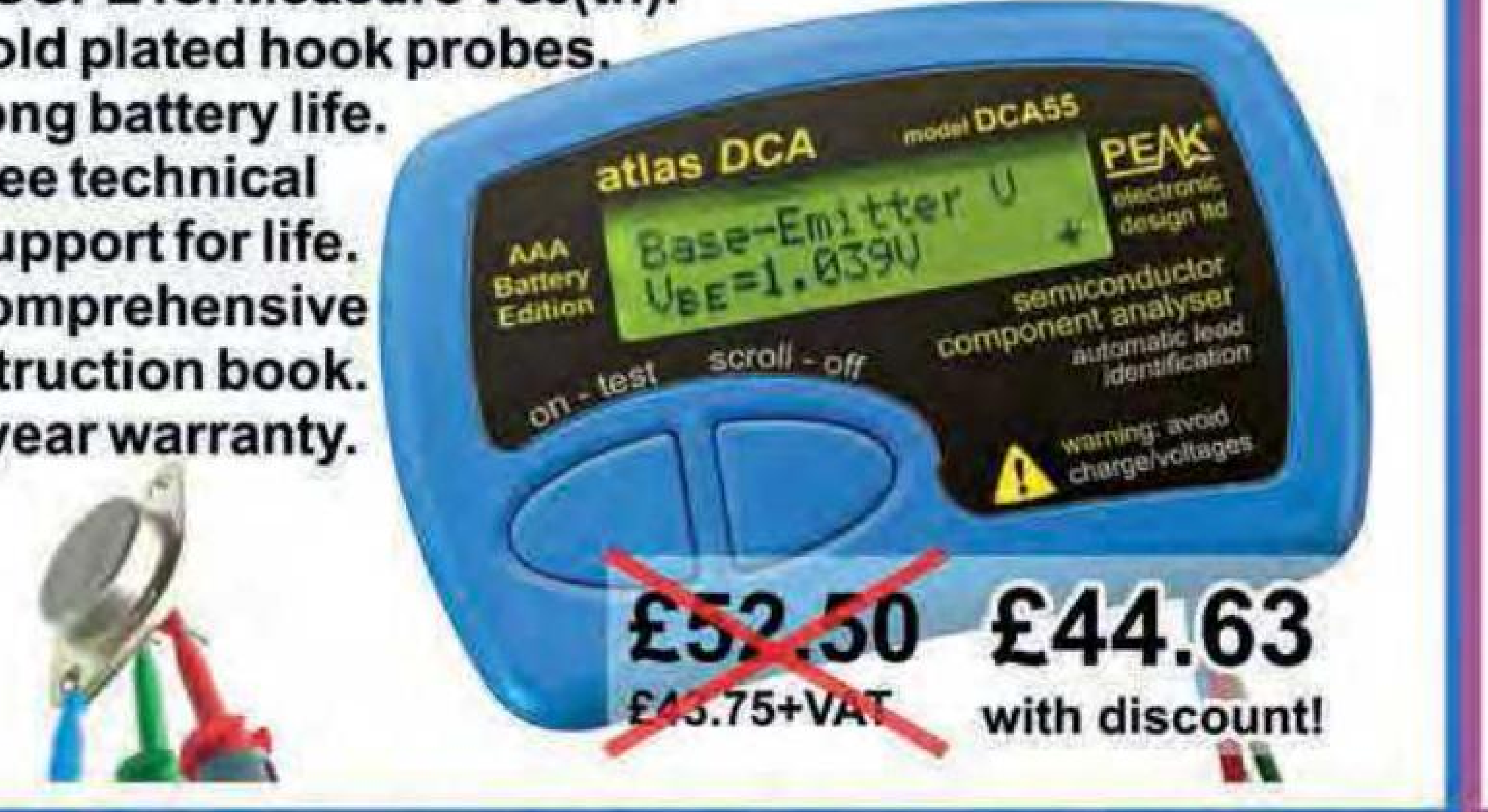
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